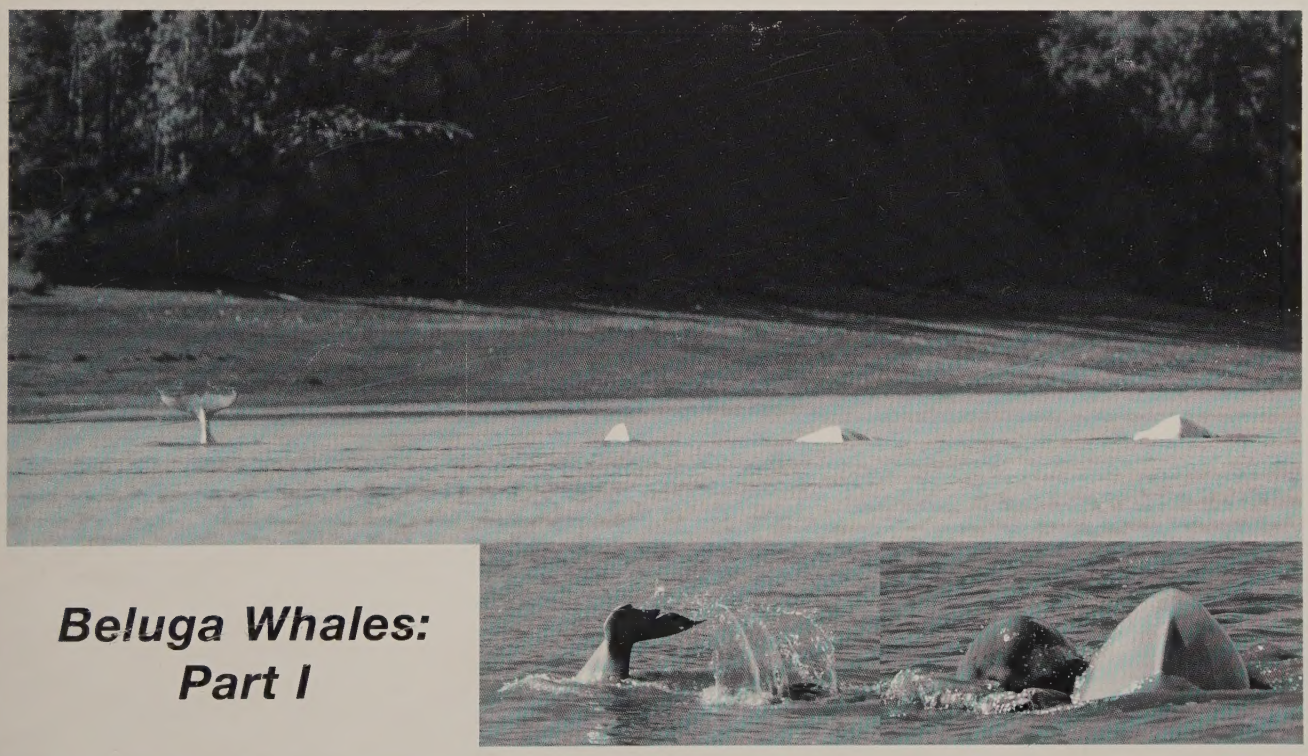
Marine Fisheries
REVIEW
Vol. 77, No. 1
2015
United States Department of Commerce



Beluga Whales: Part I

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Marine Fisheries REVIEW

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On the cover:
Beluga whales, *Delphinapterus leucas,* in Cook Inlet, Alaska. Top photo taken from shore, courtesy of Chris Garner, U.S. Army, Joint Base Elmendorf-Richardson, and bottom photos courtesy of LGL Alaska Research Associates, NMFS General Authorization LOC 481-1795-01 and MMPA-ESA research permit 14210.

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The Marine Fisheries Review (ISSN 0090-1830) is published quarterly by the Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115. Annual subscriptions are sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. The annual subscription price is $25.00 domestic, $35.00 foreign. Single copies are $9.50 domestic, $13.30 foreign. New subscriptions may be purchased online at http://bookstore.gpo.gov/products/sku/703-028-00000-4 or by mail at U.S. Government Printing Office, P.O. Box 979050, St. Louis, MO 63197-9000.

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This publication is available online at http://spo.nmfs.noaa.gov/mcontent.htm

The Status of Beluga Whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, and Surrounding Waters: Part I

Preface

It has been 15 years since publication of the special issue on beluga whales, *Delphinapterus leucas*, in the *Marine Fisheries Review* 62(3), featuring the depleted Cook Inlet, Alaska, population. That issue provided an overview of the status of this population (Moore and DeMaster, 2000) as well as papers focused on distribution (Rugh et al., 2000; Speckman and Piatt, 2000; Laidre et al., 2000), abundance (Hobbs et al., 2000a,b), habitat (Moore et al., 2000), pollutants (Becker et al., 2000), tagging (Lerczak et al., 2000; Ferrero et al., 2000), hunting (Mahoney and Shelden, 2000), and traditional knowledge (Huntington et al., 2000).

Since 2000, with a small, managed subsistence hunt, it was expected that the population would begin to show signs of recovery. Instead, the Cook Inlet population continued to decline. Articles focused on predation (Shelden et al., 2003), stranding events (Vos and Shelden, 2005), movement patterns (Hobbs et al., 2005), and habitat preferences (Goetz et al., 2007) of Cook Inlet belugas were published in several peer-reviewed journals. NOAA's National Marine Fisheries Service (NMFS) completed Status Reviews in 2006[1] and 2008[2,3] and a Conservation Plan (NMFS, 2008) just prior to listing this distinct population segment as endangered under the U.S. Endangered Species Act (ESA) (NOAA, 2008). Critical Habitat was designated in 2011 (NOAA, 2011), based in part on an observed northward contraction in range (Rugh et al., 2010) and habitat preference models (Goetz et al., 2007, 2012).

The ESA requires that Status Reviews be conducted every 5 years; therefore, in 2013, we put out a call for papers to update information presented in the *Marine Fisheries Review* 62(3) and the 2008 Status Reviews. In particular, we sought to provide a peer reviewed venue for the many research efforts as well as monitoring reports from industrial activities occurring within Cook Inlet. This has now culminated in two special issues of the *Marine Fisheries Review* devoted to beluga whales, with a focus on Cook Inlet.

This first issue includes an update of the Cook Inlet abundance and trend time series through 2012, a synopsis of Alaska beluga whale prey based on stomach content analyses, an ethogram for wild beluga whales based on studies at Eagle Bay, three papers on the Yakutat Bay beluga group, and a novel beluga monitoring project conducted on the Little Susitna River. The second issue 77(2) includes a review of spatio-temporal changes in Cook Inlet beluga distribution, a population viability analysis and extinction risk assessment, a summary of potential natural and anthropogenic threats, a calf index for Cook Inlet, the first citizen science project developed for Cook Inlet, a note on socio-sexual behavior, and two papers on behaviors observed during Port of Anchorage monitoring studies.

We hope that these contributions will provide a sound basis for future research and management of this unique species.

Kim Shelden and Rod Hobbs

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Acoustic Monitoring and Prey Association for Beluga Whale, *Delphinapterus leucas*, and Harbor Porpoise, *Phocoena phocoena*, off Two River Mouths in Yakutat Bay, Alaska

MANUEL CASTELLOTE, KATHLEEN M. STAFFORD,
A. DARCIE NEFF, and WILLIAM LUCEY

ABSTRACT—Little is known about the ecology of beluga whales, Delphinapterus leucas, *and harbor porpoises,* Phocoena phocoena, *inhabiting Yakutat Bay, Alaska. Using passive, acoustic monitoring techniques, their year-round presence was monitored during June 2012–Mar. 2013 off the mouths of two glacial rivers: Esker Creek and Grand Wash. Fishery trawl transects were run in both areas during Mar.–Aug. 2013 to assess fish and invertebrate diversity and to identify potential beluga and harbor porpoise prey. Results supported year-round presence for both species, with restricted home range for beluga and a wider distribution for porpoise. Opposite diel patterns in beluga and harbor porpoise presence suggest potential competitive overlap in prey between species. Based on trawl abundance and ubiquity, several fish and crustacean species were identified as potential prey for beluga and harbor porpoise. Results support the belief that shrimp, crab, and mysids may be an important part of beluga and porpoise diet in Yakutat. Both river mouth areas are used by harbor porpoises but their seasonality might not be driven solely by prey diversity or abundance. Beluga detection results during a coho salmon,* Oncorhynchus kisutch, *run were indicative of predation by belugas on this species during their spawning migration. This pilot study demonstrates the utility of remote, passive acoustic monitoring technology to better understand the seasonal distribution patterns and prey association of beluga and harbor porpoise in Yakutat Bay.*

Introduction

Yakutat Bay on the eastern Gulf of Alaska is a glacial fjord influenced by the activity of major tidewater glaciers at its head and is a region of high marine biodiversity. Two marine mammal species that live there year-round are the beluga whale, *Delphinapterus leucas*, and the harbor porpoise, *Phocoena phocoena*.

The exact number of belugas in Yakutat Bay is unknown, but the best present estimate is 10–12 whales (O'Corry-Crowe et al., 2015; O'Corry-Crowe[1]). Genetic studies indicate that this small group of belugas is isolated from the nearest population, in Cook Inlet; thus they may be resident in the Yakutat Bay region year-round (O'Corry-Crowe et al., 2015). Because these whales have such a restricted home range and small population size but are reproductive, they have a unique ecology (O'Corry-Crowe et al.[1, 2]). The core area for these animals appears to be Disenchantment Bay, at the far northeast end of Yakutat Bay, located between four actively calving tidewater glaciers (Fig. 1). Both opportunistic historical sightings (Laidre et al., 2000) and traditional ecological knowledge from the Tlingit Tribe (Lucey et al., 2015) suggest that belugas have inhabited Yakutat Bay since at least the 1930's, but they likely originated from Cook Inlet (O'Corry-Crowe et al., 2015).

Little is also known about the numbers and distribution of harbor porpoise in the bay, although they are seen more frequently than are beluga by the residents of Yakutat. Yakutat Bay is one of the regions in southeastern Alaska that has relatively high densities of harbor porpoises (Hobbs and Waite, 2010). Harbor porpoises are sighted both within and outside the bay in nearshore waters (Dahlheim et al., 2000; Hobbs and Waite, 2010). While there is little knowledge on historical beluga presence in Yakutat Bay, harbor porpoises have occupied the area since before human settlement and at one time were hunted for food by Yakutat Tlingit (De Laguna, 1972).

Various human activities occur within the known Yakutat beluga distribution range, including cruise ship visits, commercial fishing, marine geophysical surveys, seal hunting, and scientific activities, but none of these have been evaluated for potential impacts on this small and isolated population. Therefore, improved knowledge of Yakutat's beluga seasonal distribution and habitat use is needed to better evaluate the potential effects of anthropogenic ac-

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doi: dx.doi.org/10.7755/MFR.77.1.1

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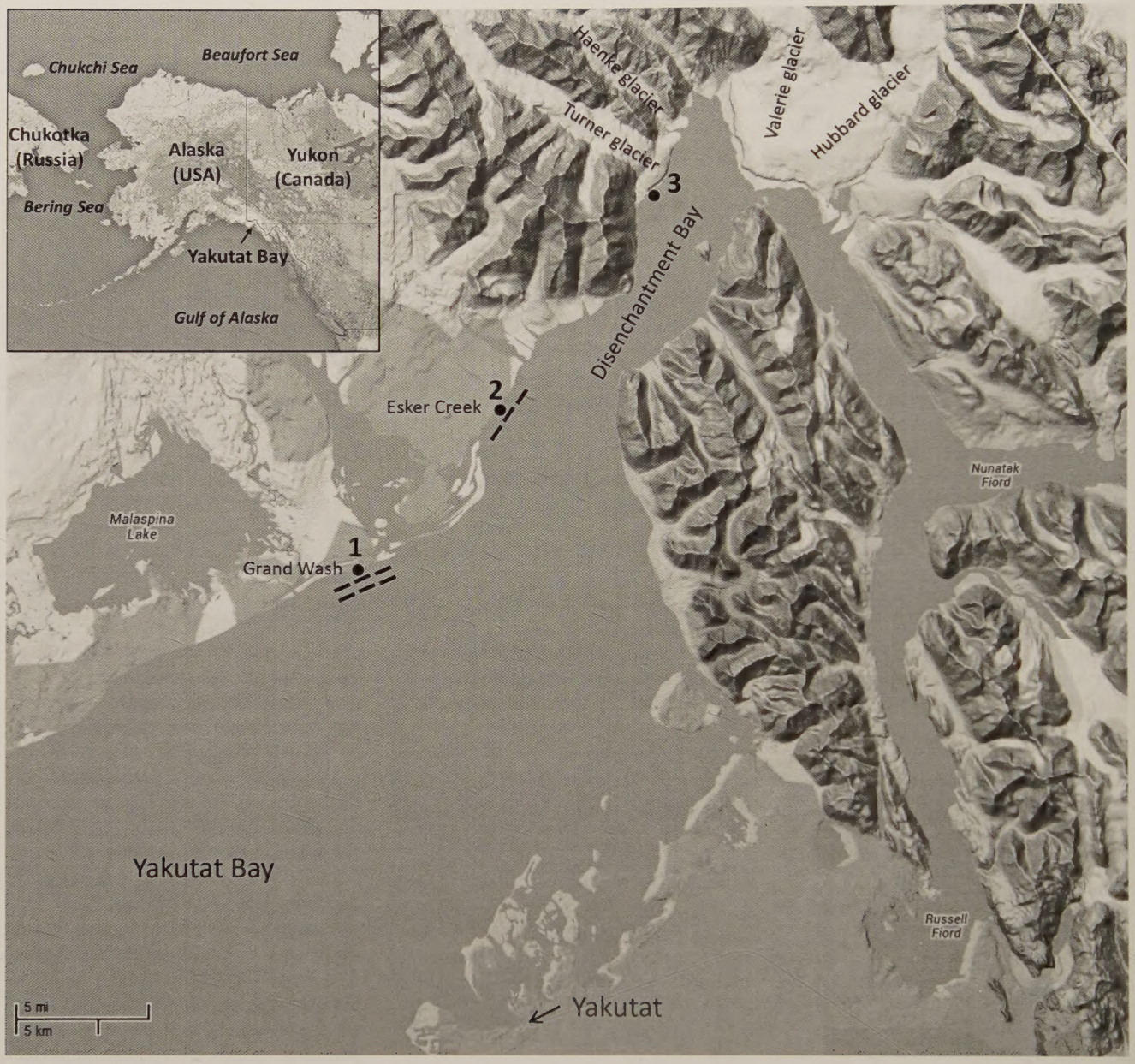

Figure 1.—Disenchantment and Yakutat Bays, mooring deployment locations (dots) and trawl transects (lines).

tivities and to define proper conservation management measures.

To study such a small, cryptic, and remote population, passive acoustic monitoring was proposed. This method has proven to be very effective for cetacean studies because it can be used in all weather conditions and seasons (Mellinger et al., 2007). Long-term monitoring of belugas in estuarine environments with moored passive acoustic recorders has proven fruitful in Cook Inlet, Alaska (Lammers et al., 2013). Therefore, echolocation loggers, a low-cost passive acoustic technology, were used to monitor for the presence of beluga and harbor porpoise to determine the seasonal and geographic usage of the waters around two river mouths, Esker Creek and Grand Wash, in Yakutat Bay.

This technology has been used successfully for monitoring both belugas and harbor porpoises (Castellote et al., 2013; Wilson et al., 2013). These two species are readily distinguished by differences in frequency range and the center frequency at which each echolocates. Beluga produce typical delphinid broad-band echolocation clicks with center frequencies between 50 kHz and 110 kHz, while harbor porpoise produce typical phocoenid nar-

row-band high frequency clicks with a center frequency of 110 to 150 kHz. (Au, 1993 ; Au et al., 1999; Lammers and Castellote, 2009; Madsen et al., 2010; Castellote et al., 2013).

The goals of this study were to determine the seasonal distribution of beluga and harbor porpoise in Yakutat and whether their presence in river mouths was related to its potential prey field.

Methods

Acoustic Monitoring

Acoustic moorings were composed of an echolocation logger (C-POD, Chelonia Ltd.[3]) that monitored continuously for cetacean echolocation signals in the range 20–160 kHz and logged the date, time, and acoustic parameters of detected signals. This instrument was attached 1 m above an acoustic release (CART, ORE Edgetech) that releases the mooring from its sacrificial anchor when activated by an acoustic signal from a deck unit. The mooring configuration was linear, with a vinyl subsurface float 1 m above the C-POD and an anchor comprised of five gravel-filled bags with a total weight of about 150 lb, 3 m below the release. The estimated C-POD detection radius for harbor porpoise is 500 m (Nuuttila et al., 2013), while larger (lower frequency) species, including beluga, can be detected out to 900 m (M. Castellote[4]).

Three acoustic moorings were deployed on 20 June 2012, one in the core area of known beluga distribution in Disenchantment Bay (by Turner Glacier), and two off the mouths of Esker Creek and Grand Wash River (Fig. 1) at depths of 27–40 m. These two glacial streams are known to be visited by belugas according to traditional knowledge (Lucey et al., 2015).

Unfortunately the mooring in Disenchantment Bay was subsumed by the advancement of Turner Glacier and lost. Therefore, only data from Esker Creek and Grand Wash River are discussed here. The moorings at Esker Creek and Grand Wash River were successfuly serviced in Oct. 2012. Data were collected for the full period in Esker Creek (20 June 2012–19 Oct. 2012), but the C-POD deployed in Grand Wash River stopped logging on 5 Sept 2012. On 7 Mar. 2013, the Grand Wash River mooring was recovered and data were collected for the full period (19 Oct. 2012–7 Mar. 2013), but the mooring flotation failed in Esker Creek and the instrument could not be recovered, limiting the monitoring effort in this location to 5 months (June–Oct. 2012).

C-POD data were analyzed with custom written software from the manufacturer (CPOD.exe version 2.043, Chelonia Ltd.) using the default settings; i.e., "Hi and Mod train quality," "all cetacean species," unmodified "train values," and "click filters." All automatic detections and their click train type classification (narrowband high frequency clicks, termed NBHF, or other cetaceans' clicks) were manually validated to properly distinguish among echolocation detections of belugas and porpoises. Manual analysis permitted the exclusion of multiple false detections caused by noise, which were easily recognized by the broad frequency coverage and lack of coherence in temporal scale, pulse bandwidth, number of cycles, and envelope. Misclassification of porpoise echolocation as "other cetaceans" instead of NBHF was never encountered in the processed data, probably due to the considerable differences in frequency range and click bandwidth between porpoise and beluga echolocation (Au, 1993).

Beluga and porpoise detection results were converted into detection positive hours (hours with at least one echolocation click train, DPH). DPH were summed for each day to obtain DPH/day and further summed for each month to obtain DPH/month. Diel patterns were evaluated by calculating the frequency of occurrence of DPH by time of day.

Time intervals between clicks in echolocation click trains, termed interclick intervals (ICI), have been used as a behavioral indicator in several odontocetes, including harbor porpoise (DeRuiter et al., 2009; Verfuss et al., 2009) and beluga (Roy et al., 2010; Castellote et al., 2013). Previous studies have reported the occurrence of click trains during porpoise foraging behavior, with progressively decreasing ICI's ending in a high rate terminal "buzz", with ICI's close to or less than 2 ms during the final prey capture (Verboom and Kastelein, 2003; DeRuiter et al., 2009; Miller, 2010; Wisniewska et al., 2012). This same echolocation behavior has been suggested for feeding belugas (Roy et al., 2010; Castellote et al., 2013).

Several studies have shown the utility of C-POD data to identify feeding behavior based on this acoustic parameter (Castellote et al., 2013; Nuuttila et al., 2013; Pirotta et al., 2013). Therefore, minumum ICI values for each beluga and harbor porpoise click train logged by the C-POD's in Esker Creek and Grand Wash River were analyzed to identify those containing terminal buzzes. All click trains with ICI's between 1 and 2 ms were manually inspected to confirm the presence of a buzz in the click sequence; click trains with ICI's between 1 and 2 ms but without a buzz were not considered feeding buzzes (Castellote et al. 2013). The percentage of feeding buzzes over the total number of click trains detected per month for each species was calculated.

Salmon Run Data

Pacific salmon, *Oncorhynchus* spp., run data were obtained from the Alaska Department of Fish and Game for Esker Creek and Grand Wash River for the 2012 season. A coho salmon, *O. kisutch*, run occurred in Esker Creek from 25 Aug. until 5 Oct., and no salmon runs were detected in Grand Wash River during the study period. To evaluate if the presence of a coho salmon run in Esker Creek had any effect on cetacean presence, DPH/day was grouped into three periods:

[3]Mention of trade names or commercial products does not imply endorsement by the National Marine Fisheries Service, NOAA.

[4]Castellote, M. Feb. 2011. Unpubl. data on file at NOAA, NMFS, Alaska Fish. Sci. Ctr., National Marine Mammal Lab., Seattle, WA 98115.

pre-salmon run (11–24 Aug.), peak-salmon run (1–28 Sept.), and post-salmon run (6–19 Oct.). Differences in the DPH/day for both beluga and harbor porpoise between the three periods were tested using Kruskal–Wallis one-way analysis of variance by ranks and post hoc paired comparisons. Median percentiles and maximum/minimum DPH by day for both beluga and harbor porpoise for each period were calculated and plotted for comparison.

To evaluate any evidence of cetacean foraging behavior on the coho salmon run in Esker Creek, presence of foraging buzzes (click trains containing a terminal buzz with ICI between 1 and 2 ms) was assessed for both beluga and harbor porpoise in the same three periods: pre-, peak-, and post-salmon run.

Fishery Trawl Data

Fish and invertebrate data were collected in 2013 using a bottom trawl at both Esker Creek and Grand Wash River (Fig. 1) as part of a separate study conducted by the City and Borough of Yakutat in cooperation with the U.S. Army Corps of Engineers. The trawl mouth was 2.6 m wide by 1.2 m deep, and it was attached to a 6.3 m long bridle of 2.1 cm braided line. The trawl had two weighted doors (33 cm by 61 cm) and was 5.2 m in total length; inside the outer skirt of 29 mm stretch mesh was a 1.7 m long cod end of 3.2 mm stretch mesh. The trawl was towed at about 2–2.5 kt for 5 min. The scope of the tow line (1.6 cm polypropylene) was 3:1.

Trawl transects were established near the Esker Creek and Grand Wash River acoustic monitoring sites. Esker Creek had three transects in 10–12 m of water, each of which was trawled once on 22 June, 24 July, and 19 Aug. 2013. Grand Wash River had six transects in 7–12 m of water, each of which was trawled once on 28 Mar., 27 May, 22 June, 24 July, and 19 Aug. 2013. GPS locations were recorded at the beginning and end of each trawl.

After trawl retrieval, the entire catch was sorted into live tanks, and individually sorted to lowest taxon. A total count was taken and a subsample of up to 50 individuals was measured to the nearest millimeter for total length. Life stage was assigned to fish in the field based on ontogenetic characteristics. Fish were considered adults when their length exceeded species-specific estimates of length-at-first-maturity (Bisby et al., 2012). Invertebrates were also individually counted and classified to the lowest possible taxon.

Catch data are expressed in relative abundance signified by catch per unit of effort (CPUE; i.e., number of fish captured per trawl) and percent frequency of occurrence (FO; i.e., number of tows in which species was captured). To identify potential prey species with similar seasonality to beluga and porpoise presence, beluga and porpoise DPH/day from 2012 were averaged for each month and qualitatively compared to CPUE/month from 2013 for the overall fish and invertebrate catch based on the assumption that monthly relative abundance and ubiquity in benthic prey did not vary greatly between 2012 and 2013.

Results

Beluga and harbor porpoise presence were acoustically monitored for 120 days in Esker Creek and 261 days in Grand Wash River. Acoustic detections of both beluga and harbor porpoise echolocation were identified in each location. Belugas were detected at both locations, but were more common at Esker Creek. Beluga presence averaged 4 h per day over the entire time period in Esker Creek with most activity occurring from June to Sept. at peaks of 14–16 DPH/day, and fewer detections later in the year (Fig. 2A). Belugas were only detected during 2 h at Grand Wash River on 12 Nov. 2012 (Fig. 2B). Harbor porpoise were present in both locations for the entire period with an average of 10 DPH/day in Esker Creek and 17 DPH/day in Grand Wash River. Porpoise presence increased in July and early Aug. in Grand Wash River and in Oct. in Esker Creek (Fig. 2).

Diel differences in acoustic activity were examined for both beluga and harbor porpoise. The distribution of DPH per time of day in Esker Creek suggests that beluga visited this area more often between 0700 to 2200 h (local Alaska time), and harbor porpoise visited between 0000 and 0700 h (Fig. 3). No diel pattern in porpoise presence was identified in Grand Wash River.

A total of at least 19 fish species and 12 invertebrate species were captured in the benthic trawls in the same regions in which C-POD's were deployed the previous year (Table 1). Unlike the salmon data, trawl data were not available for 2012 when the acoustic monitoring took place; therefore, 2013 data were only used to determine what possible prey species occur in the region at the same time of the year as beluga or harbor porpoise. Beluga DPH in Esker Creek showed a gradual decreasing pattern in monthly presence, with highest values in June and lowest in Aug. (Fig. 4A). Total CPUE/month for fish also peaked in June but did not follow a gradual decreasing pattern. For invertebrates, total CPUE/month peaked in July. There was no obvious association between beluga DPH and total prey CPUE/month.

Monthly porpoise DPH and total fish CPUE in Esker Creek had inverted patterns when compared to each other (Fig. 4A). However, total invertebrate CPUE had a similar pattern to porpoise monthly presence. In Grand Wash River, neither total fish CPUE nor invertebrate CPUE per month had any relationship to monthly porpoise DPH (Fig. 4B).

Percentages of foraging buzz detections were obtained for belugas and harbor porpoises in Esker Creek from June to Oct. 2012, and for harbor porpoises in Grand Wash River from Jan. to Mar. 2013 and from June to Dec. 2013 (Fig. 5). The highest percentage of foraging buzzes was found in Aug. and Sept. for both species in Esker Creek. This peak occurred slightly later (Sept. and Oct.) for harbor porpoises in Grand Wash River. The proportion of detected foraging buzzes was highest for harbor porpoises in Esker Creek, with an average of 3.6%

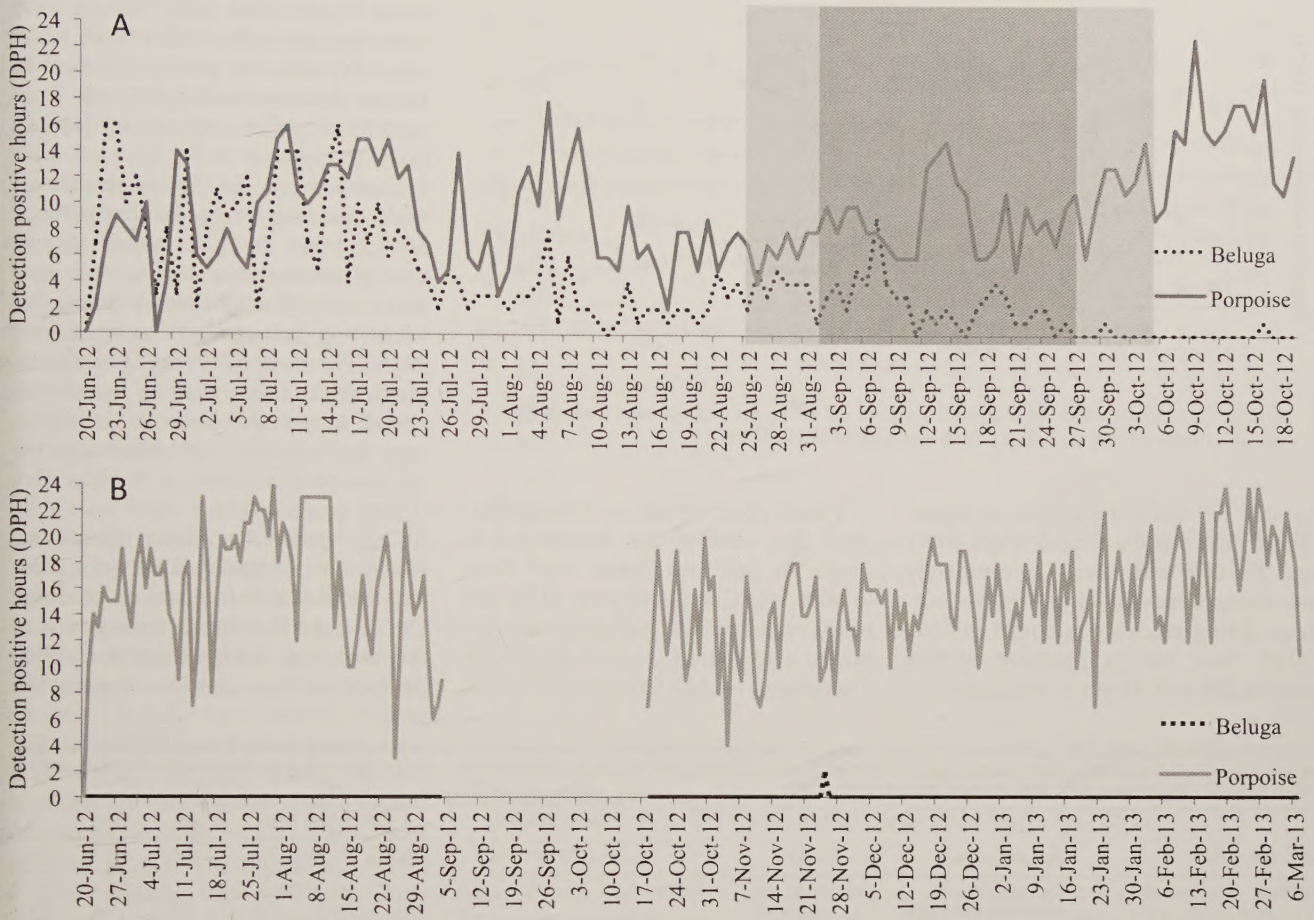

Figure 2.—Detected positive hours (DPH) per day for beluga (dashed line) and harbor porpoise (gray line) for the full deployment period in A) Esker Creek and B) Grand Wash River. In Esker Creek, the coho salmon run period is denoted by a light gray block with peak-run period by a dark gray block (note the different date scales between panels).

(max 5.6%), followed by harbor porpoises in Grand Wash River (average of 2.3%, max 2.9%), and belugas in Esker Creek (average of 0.2%, max 0.4%).

When DPH per day was grouped by salmon run period (pre-, peak-, and post-), highly significant differences were found between periods for both beluga ($H_{2,56}$=22.6, $p<0.01$) and harbor porpoise DPH ($H_{2,56}$=31.3, $p<0.01$). Post-hoc paired comparisons highlighted differences between the post-run period and the two other periods, but no differences between the pre- and peak-run periods for both beluga and harbor porpoise. There were significantly more beluga DPH during the pre- and peak- salmon run periods than during the post-run period, and significantly more porpoise DPH during the post-run period than during the pre- and peak-run periods (Fig. 6).

Only five beluga foraging buzzes were identified during the salmon run periods (pre-, peak-, and post-), all falling within the peak salmon run. No foraging buzzes were identified for harbor porpoises in any of the three salmon run periods.

Discussion

Beluga

Beluga presence in the Grand Wash River area was limited to a single detection on 25 Nov. 2012 composed of multiple click trains over 2 h. The overall CPUE of both fish and invertebrates at Grand Wash River was higher than at Esker Creek (Fig. 2); assuming 2012 and 2013 were similar in prey occurrence, a lack of beluga detections in this region was therefore not due to a lack of prey. Opportunistic sightings of belugas have rarely been reported outside Disenchantment Bay (Lucey et al., 2015), and the data presented here confirm that belugas rarely move south of the Disenchantment Bay area.

Results from the mooring in Esker Creek, at the entrance of Disenchantment Bay, showed continuous presence of belugas from June to Oct. 2012, suggesting that this area is an important part of their summer distribution, and that the limit of the core

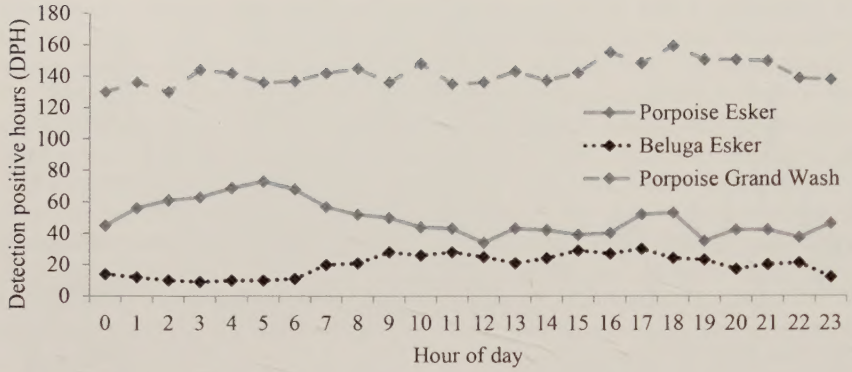

Figure 3.—Distribution of summed number of DPH for beluga and harbor porpoise by hour of day in Esker Creek and Grand Wash River.

habitat for Yakutat belugas is somewhere between the Grand Wash River and Esker Creek sites. Unfortunately the Esker Creek mooring did not surface during recovery attempts in June 2013; thus, beluga presence in this area in fall and winter is unknown.

Visual observations in Disenchantment Bay confirm that beluga movements in this area occur very close to shore (O'Corry-Crowe et al.[1]), and most opportunistic sightings are reported near shore (Lucey et al., 2015). Therefore, if belugas moved south from Esker Creek they should have been detected in the Grand Wash River area. However, the gradual decrease in beluga presence in Esker Creek from June to early Oct. and a lack of detections throughout Oct., coupled with 2 h of activity in Nov. at the Grand Wash mooring, suggests that belugas do not leave Disenchantment Bay in the fall but may move to another area north or northeast of Esker Creek. Alternatively, belugas in Disenchantment Bay could move out of the Disenchantment area in fall, following the eastern shoreline toward Yakutat. However, very few sightings have been reported on the eastern shore of Yakutat Bay (Lucey et al., 2015).

Only data from Esker Creek allowed for a comparison between beluga DPH/day and fish and invertebrate CPUE and FO. It is interesting to note that even with a higher amount of fish density and prey species composition,

Table 1.—Total catch, mean catch per unit of effort (CPUE, unit = tow), and percent frequency of occurrence (FO) of fish and invertebrate taxa captured with a bottom trawl at Esker Creek and Grand Wash River, Yakutat Bay, Alaska. Species richness values are listed in the FO total cells. A total of 35 trawls were made during June–Aug., 2013 at Esker Creek (n = 9) and Mar.–Aug., 2013 at Grand Wash River (n = 26).

			Esker Creek			Grand Wash River			Total		
Common name	Scientific name	Family	Catch	CPUE	FO	Catch	CPUE	FO	Catch	CPUE	FO
Fishes											
Longfin smelt	*Spirinchus thaleichthys*	Osmeridae				327	12.6	85	327	9.3	63
Pacific tomcod	*Microgadus proximus*	Gadidae	33	3.7	56	280	10.8	65	313	8.9	63
Capelin	*Mallotus villosus*	Osmeridae	1	0.1	11	164	6.3	38	165	4.7	31
Snake prickleback	*Lumpenus sagitta*	Stichaeidae	47	5.2	56	1	0.0	4	48	1.4	17
Sturgeon poacher	*Podothecus accipenserinus*	Agonidae	8	0.9	33	22	0.8	38	30	0.9	37
Pricklebreast poacher	*Stellerina xyosterna*	Agonidae				23	0.9	35	23	0.7	26
Pacific sandfish	*Trichodon trichodon*	Trichodontidae	3	0.3	22	11	0.4	23	14	0.4	23
Butter sole	*Isopsetta isolepis*	Pleuronectidae	1	0.1	11	10	0.4	23	11	0.3	20
Showy snailfish	*Liparis pulchellus*	Liparidae	1	0.1	11	9	0.3	12	10	0.3	11
Juvenile snailfish		Liparidae	1	0.1	11	7	0.3	15	8	0.2	14
Scalyhead sculpin	*Artedius harringtoni*	Cottidae	7	0.8	33				7	0.2	9
Starry flounder	*Platichthys stellatus*	Pleuronectidae				5	0.2	19	5	0.1	14
Sand sole	*Psettichthys melanostictus*	Pleuronectidae	1	0.1	11	3	0.1	8	4	0.1	9
Spinyhead sculpin	*Dasycottus setiger*	Psychrolutidae	4	0.4	33				4	0.1	9
Eulachon	*Thaleichthys pacificus*	Osmeridae				2	0.1	4	2	0.1	3
Fish larvae		Division Teleostei	2	0.2	11				2	0.1	3
Northern rock sole	*Lepidopsetta polyxystra*	Pleuronectidae	2	0.2	11				2	0.1	3
Buffalo sculpin	*Enophrys bison*	Cottidae	1	0.1	11				1	0.0	3
English sole	*Parophrys vetulus*	Pleuronectidae				1	0.0	4	1	0.0	3
Pacific spiny lumpsucker	*Eumicrotremus orbis*	Cyclopteridae	1	0.1	11				1	0.0	3
Prickleback larvae		Stichaeidae				1	0.0	4	1	0.0	3
Saffron cod	*Eleginus gracilis*	Gadidae				1	0.0	4	1	0.0	3
Smelt larvae		Osmeridae				1	0.0	4	1	0.0	3
			113	12.6	13	868	33.4	14	981	28.0	19
Invertebrates											
Mysid	*Neomysis* spp.	Mysidae	72	8.0	78	647	24.9	88	719	20.5	86
Crangon shrimp	*Crangon* spp.	Crangonidae	164	18.2	78	421	16.2	81	585	16.7	80
Pink shrimp	*Pandalus eous*	Pandalidae	241	26.8	56				241	6.9	14
Dungeness crab	*Cancer magister*	Cancridae	33	3.7	67	47	1.8	31	80	2.3	40
Unidentified jellyfish		Class Scyphozoa				74	2.8	31	74	2.1	23
Dock shrimp	*Pandalus danae*	Pandalidae	7	0.8	22				7	0.2	6
Unidentified copepod		Subclass Copepoda				6	0.2	4	6	0.2	3
Pacific glass shrimp	*Pasiphaea pacifica*	Pasiphaeidae	1	0.1	11	1	0.0	4	2	0.1	6
Unidentified amphipod		Order Gammeridea				2	0.1	4	2	0.1	3
Unidentified Pandalid shrimp	*Pandalus* sp.	Pandalidae				2	0.1	4	2	0.1	3
Coonstripe shrimp	*Pandalus hypsinotus*	Pandalidae	1	0.1	11				1	0.0	3
Hermit crab	*Pagurus* sp.	Paguridae				1	0.0	4	1	0.0	3
Unidentified worm		Phylum Annelida				1	0.0	4	1	0.0	3
			519	57.7	7	1,202	46.1	10	1,721	49.2	12

belugas were rarely detected off Grand Wash River. The occasional presence of transient killer whales, *Orcinus orca*, may play an important role in limiting beluga distribution in Yakutat Bay.

Belugas could be more exposed to a higher risk of predation in river mouths further west of Esker Creek. Features such as water turbidity and presence of ice might be important for beluga to avoid predation by killer whales (Castellote et al., 2013). In this regard, Esker Creek is still highly influenced by the conditions of Disenchantment Bay while Yakutat Bay conditions have a stronger influence on the Grand Wash River area.

A recent review of beluga diet in Alaska by Quakenbush et al. (2015) analyzed stomach contents from 355 belugas taken in subsistence harvests or from belugas found dead from all five recognized stocks (Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet). Diet was highly variable among stocks, highlighting the opportunistic nature of beluga feeding habits. The northernmost stocks feed mostly on Arctic cod, *Boreogadus saida;* shrimp, *Crangon* spp., *Pandalus* spp., and *Pasiphaea pacifica*; and octopus, *Benthoctopus* spp. To the south, saffron cod, *Eleginus gracilis,* replaces Arctic cod, and octopus is no longer prevalent. For the two southernmost stocks (Bristol Bay and Cook Inlet), Arctic and saffron cod are largely replaced by salmon and smelt. Shrimp are common prey for all beluga stocks in Alaska.

When comparing the CPUE and FO for fish and invertebrate species obtained in the Esker Creek trawls and the prey species described in Quakenbush et al. (2015), snake prickleback, *Lumpenus sagitta*, (found in the Cook Inlet beluga diet), northern rock sole, *Lepidopsetta polyxystra*, (found in the eastern Bering Sea and Bristol Bay beluga diets), and shrimp (pink shrimp, *Pandalus eous*, and crangon shrimp, *Crangon* spp., found in all beluga stock diets), were very abundant and ubiquitous in the Esker Creek area and thus potentially eaten by beluga. Crabs (Majidae, *Hyas lyratus*, *Chionocetes bairdi*, and *Chionocetes opilio)* are part of the beluga diet in all stocks except in Kotzebue; dungeness crab, *Metacarcinus magister*, was also an important contributor to the total CPUE with high FO in Esker Creek. Shrimps and crabs were very abundant in all months sampled in both river areas, and might therefore be important prey species for Yakutat beluga. Mysids have been described as part of the beluga diet in Kotzebue and Cook Inlet (Quakenbush et al., 2015) and were among the most abundant invertebrates collected in the trawls in both locations and all months. Thus, it is possible that Yakutat belugas also feed on these crustaceans.

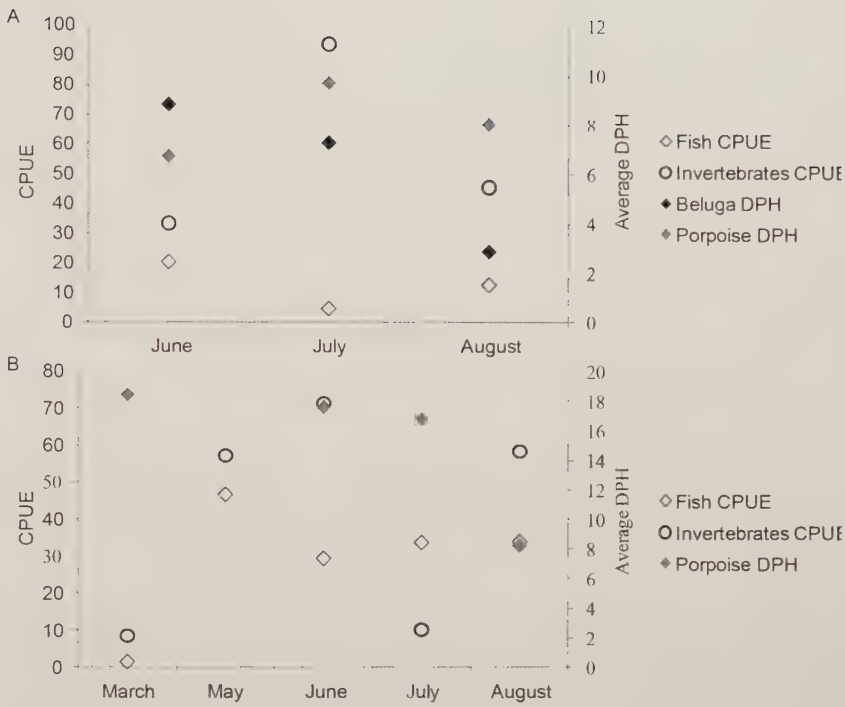

Figure 4.—A) Monthly values in Esker Creek for overall CPUE for fish and invertebrates in June–Aug. 2013 and DPH for beluga and porpoise in June–Aug. 2012. B) Monthly values in Grand Wash River for overall CPUE for fish and invertebrates in Mar.–Aug. 2013 and DPH for porpoise in Mar.–Aug. 2012.

Pacific tomcod, *Microgadus proximus*, was a dominant species with high FO in trawls from both river areas, and although this species has not been identified as beluga prey, it is similar to Arctic and saffron cod which are important beluga prey.

The presence of coho salmon in Esker Creek influenced the number of beluga DPH/day. There were significant differences between the salmon run and the 2 weeks after the run, but not with the 2 weeks before the run. Figure 6 shows a slight increase in DPH/day during the peak salmon run, but DPH/day during the days prior to the salmon run were also high. The percentage of beluga foraging buzzes in Esker Creek was highest in Aug. and Sept., concurrent with the coho salmon run (Fig. 5), although foraging buzzes were not detected during the 2 weeks prior to the onset of the run or during the 2 weeks after the run. These results suggest that while the increase in beluga presence in Esker Creek occurred several days before the onset of the salmon run, foraging behavior did not increase until coho salmon started running upstream.

Pacific salmon behavior during their spawning migration includes periods of osmoregulation and thermoregula-

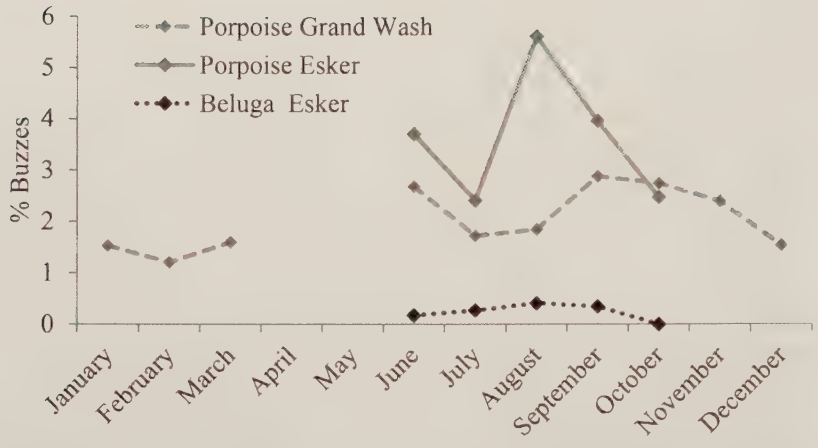

Figure 5.—Percentage of beluga and harbor porpoise foraging buzzes (click trains containing terminal buzzes with ICI between 1 and 2 ms) per month in Esker Creek and Grand Wash River.

tion prior to river entry, which might involve milling behavior for extended periods of time (Banks, 1969). River entry is also affected by flow characteristics, and salmon might start their upriver migration only at specific flow rates (Jonsson, 1991). To our knowledge, the relationship between salmon behavior during these acclimation periods and beluga foraging behavior has never been studied. These results could be indicative of beluga preying on coho salmon under specific behavioral conditions. Accessibility to coho salmon (i.e., how easy they are to capture), more than presence or density, at Esker Creek mouth might better explain these results and should be explored in future studies.

Beluga presence in Esker Creek was highest in June and July. However, the percentage of foraging buzzes was lower than during the coho salmon run in Aug. and Sept., suggesting that foraging was not the predominant behavioral state or that foraging was directed towards other types of prey, such as benthic invertebrates. If echolocation is directed towards the bottom, the chances of detecting foraging buzzes are reduced because of the high directionality of this type of acoustic signal, unless the instrument is deployed in the same plane as the targeted prey. In any case, the obtained percentages of foraging buzzes should be considered an underestimation of their real occurrence, as only a small fraction of these signals might get logged by the C-POD. Additional monitoring techniques (e.g., behavioral observations and acoustic tags) are required to help elucidate what prey and foraging behavior is preferred by beluga in Esker Creek.

Harbor Porpoise

Harbor porpoise were regularly detected in both Esker Creek and Grand Wash River mouth areas. However, the DPH was higher at Grand Wash River, both on a seasonal (Fig. 2) and daily basis (Fig. 3). Although harbor porpoise presence was continuous in both the Esker Creek and Grand Wash River areas for the entire sampling period, monthly variation in porpoise detections did not match variations in fish or invertebrate CPUE/month in either sampling location. This suggests that although both areas are frequented by porpoises, changes in fish and/or invertebrate diversity or abundance may not affect foraging resources for porpoises, reinforcing the opportunistic nature of this species' foraging behavior. These results agree with data from surveys conducted in southeastern Alaska just south of Yakutat Bay, where harbor porpoise did not show any seasonality in their occurrence, and tended to have somewhat restricted distributions (Dahlheim et al., 2009).

Some fish and invertebrate species present in the Esker Creek trawls have been identified in both river areas as potential prey items for Yakutat harbor porpoise. Mysids and crangon shrimp dominated the total CPUE in Grand Wash River, and together with pink shrimp dominated in Esker Creek. Their FO was among the highest for all three groups, together with dungeness crab. It is interesting to note that the single Yakutat porpoise stomach contents analyzed to date showed a significant amount of shrimp, primarily crangon shrimp (ADFG[5]). Other species known to be part of the porpoise diet in Alaska are pink salmon, *O. gorbuscha*; walleye pollock, *Theragra chalcogramma;* saffron cod, Pacific sand lance, *Ammodytes hexapterus*; and Pacific sandfish, *Trichodon trichodon*. Other prey species from the stomach obtained in Yakutat are surf smelt, *Hypomesus pretiosus;* eulachon, *Thaleichthys pacificus;* and Pacific herring, *Clupea pallasii* (ADFG[6]). Yet, from all these known fish prey species, only Pacific sandfish was caught in trawls in both river areas, but in very small numbers. Pacific herring, pink salmon, Pacific sand lance, and walleye pollock were not caught in trawls.

However, other fish species that have not been identified as part of the harbor porpoise diet were abundant and ubiquitous in the trawls, including Pacific tomcod (dominant in both river areas), longfin smelt, *Spirinchus thaleichthys*, and capelin (both dominant in Grand Wash River), and snake prickleback (dominant in Esker Creek). These species could well be part of the Yakutat harbor porpoise diet as similar species have been identified in harbor porpoise stomach contents. Similar to the beluga results in Esker Creek in June and July, harbor porpoise were abundant in Oct., but the percentage of foraging buzzes was

[5]ADFG. Oct. 2011. Unpub. data on file at Alaska Dep. of Fish and Game.

[6]ADFG. Oct. 2011. 11 stomachs since 2003. Unpub. data on file at Alaska Dep. of Fish and Game.

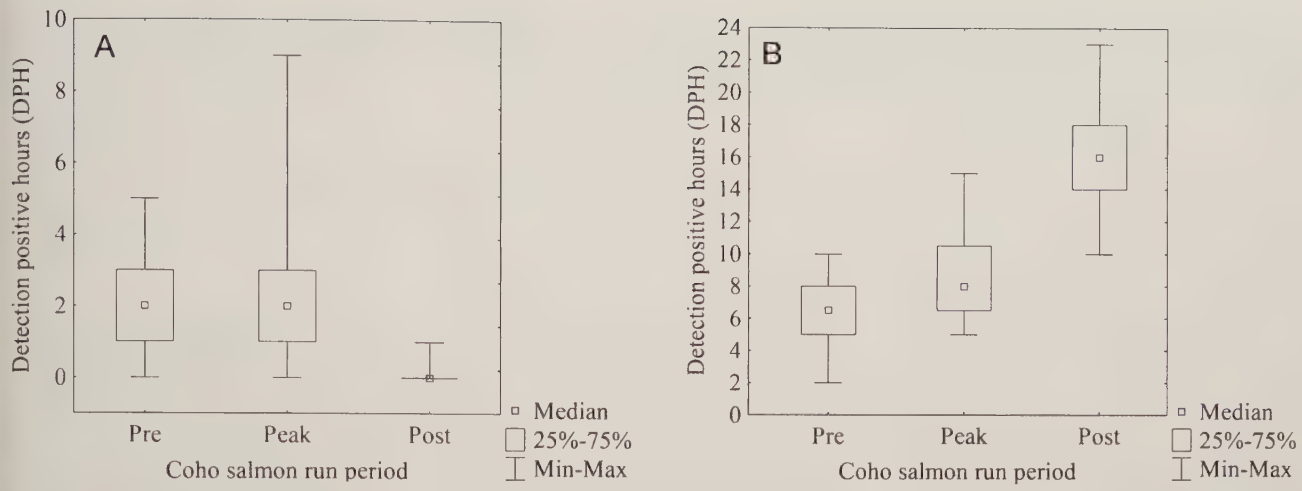

Figure 6.—Median, percentiles, and maximum/minimum DPH/day for A) beluga and B) harbor porpoise, and the salmon run periods (pre-, peak-, post-) in Esker Creek.

lower than in Aug. and Sept., which might reflect differences in foraging strategies or less foraging behavior.

Diel Patterns and Ecological Niche Separation

Diel patterns in beluga and harbor porpoise presence were only observed in Esker Creek (Fig. 3). Beluga had a preference for this site at night when harbor porpoise detections were lower. This opposite diel pattern between both species in Esker Creek and the lack of a pattern in Grand Wash River for harbor porpoise suggests the possibility of competitive overlap in prey between beluga and harbor porpoise. Harbor porpoise might actively avoid Esker Creek when beluga are present. In fact, there were very few occurrences in which both species were acoustically detected within the same hour in Esker Creek, and the few beluga detections in Grand Wash River did not coincide with harbor porpoise detections.

Both species share common prey species such as crangon shrimp, walleye pollock, saffron cod, Pacific sand lance, Pacific sandfish, surf smelt, eulachon, and Pacific herring (Quakenbush et al., 2015; ADFG[6]), several of which were trawled in the Esker Creek transects. Foraging for the same prey at different times is a successful strategy to maintain different ecological niches when two ecologically similar species coexist (Schoener, 1974; Pianka, 1976).

There was no statistical relationship between porpoise presence and coho salmon primarily because porpoise detections increased at the end of the salmon run (Fig. 6). Therefore it is not clear that coho salmon are prey for harbor porpoise in this area. While the percentage of foraging buzzes was highest in Aug. and Sept., during the coho salmon run months (Fig. 5), foraging buzzes occurred before or after the peak salmon run period, and not during the peak period, as opposed to the beluga results.

Foraging beluga may displace harbor porpoise during the peak salmon run in the Disenchantment Bay area as part of their competitive interaction. Alternatively, harbor porpoise may exploit other prey species present in Esker Creek concurrently with coho salmon.

Based on our results, high biomass values and the availability of known beluga prey in the Grand Wash River area does not seem to attract beluga. Similarly, harbor porpoise seasonality in Esker Creek and Grand Wash River areas has little relationship to the presence of known prey species. However, the presence of a coho salmon run in Esker Creek might be a significant driver for beluga and merits further consideration because this area could be of biological value for the survival of this small population of Yakutat beluga. Considering the unique conditions in which this isolated group of beluga live, understanding their habitat preferences and the potential link to prey seasonality within Disenchantment Bay should be considered a priority.

Conclusions

Passive acoustic monitoring of Yakutat beluga and harbor porpoise, although technically challenging, has proven to be feasible and effective. Lessons have been learned regarding mooring design that will improve the recovery success of future monitoring efforts. The core habitat area of Yakutat belugas is a challenging study area as it encompasses active tidewater glaciers, high sediment transport, and shifting river mouths.

Future research efforts should consider deployment of passive acoustic instrumentation in the deeper, central region of the fjord to prevent mooring interactions with ice. Data from the Turner Glacier mooring would have provided valuable information on beluga distribution changes and seasonal presence in their presumed core habitat.

Beluga likely inhabit Disenchantment Bay year-round, seldom venturing into southern areas of Yakutat Bay. Based in terms of abundance and ubiquity from trawl data collected in June–Aug. 2013 in Esker Creek and Grand Wash River, and 2012 salmon run data, coho salmon, Pacific tomcod, snake prickleback, northern rock sole, crangon shrimp, pink shrimp, mysids, and dungeness crab were identified as potential prey species for Yakutat beluga.

Both the Esker Creek and Grand Wash River areas are used by harbor porpoise, but their seasonality might not be driven solely by prey diversity or abundance. Porpoise might also prey on Pacific tomcod, longfin smelt, capelin, snake prickleback, crangon shrimp, pink shrimp, and mysids.

Some of these taxa have not yet been described as part of the beluga or harbor porpoise diet in Alaska. The results presented here support the idea that both species are highly opportunistic in their feeding habits and invertebrates might be an important part of both beluga and harbor porpoise diets in Yakutat Bay. It is strongly recommended that year-round passive acoustic monitoring be used in Yakutat Bay as this study demonstrates the applicability of using this cost-effective remote monitoring technique to better understand the distribution, seasonal presence, habitat preference, and potential diet of Yakutat beluga and harbor porpoise.

Acknowledgments

Funding for this research was provided by U.S. National Park Service grant WRST-00136 under permit #WRST-2011-SCI-0002. Field work was conducted under NOAA Scientific Research Permit 14245 issued to the NMFS National Marine Mammal Laboratory. The fisheries trawl study was conducted under ADFG Fish Resource Permit CF-13-039 by the City and Borough of Yakutat in cooperation with Chris Hoffman of the U.S. Army Corps of Engineers. We are grateful to Erving Grass (Yakutat Harbor Master) and Kayla Drumm (Yakutat High School Intern) for all their assistance.

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Estimated Abundance and Trend in Aerial Counts of Beluga Whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994–2012

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ABSTRACT—Aerial surveys of beluga whales, Delphinapterus leucas, *have been conducted annually in Cook Inlet, Alaska, from 1993 to 2012. Beluga whales were seen near the coast and within river mouths in all years, with nearly all of the sightings in the northernmost portions of the inlet after 2000. In this paper, we revisit abundance estimates from 1994 to 2012 and present changes in methods and statistical analyses that have occurred since an earlier publication in 2000. Our objectives include a reanalysis of the abundance estimates over the 19-year aerial survey time series (1994–2012), revising the population trajectory through 2012, and estimating population trend rates for endangered Cook Inlet beluga whales. Annual surveys documented a decline of nearly 50% between 1994 and 1998 from an estimated 653 (CV = 0.24) whales to 347 (CV = 0.17) whales. With a very limited hunt (5 whales total taken between 1999 and 2012), the anticipated recovery at a rate of at least 2% per year did not materialize. Instead, from 1999 to 2012, the rate of decline has been -1.60% (SE = 0.75%) per year, with a 97% probability that the growth rate is declining (i.e., less than zero) and a 99.9% probability that the growth rate is less than +2% per year.*

Introduction

In general, beluga whales, *Delphinapterus leucas*, have strong site fidelity to natal areas and very low dispersal rates (O'Corry-Crowe, 2002). In Alaska, these natal areas occur in the Beaufort Sea, Chukchi Sea, Norton Sound, Bristol Bay, and Cook Inlet. Geographically separated from beluga whale populations in western Alaska, Cook Inlet belugas are genetically distinct (O'Corry-Crowe et al., 1997) and are rarely observed in waters outside the inlet (Laidre et al., 2000). The closest beluga whale population is in Bristol Bay (Lowry et al., 2008), 1,500 km away by sea and separated by the Alaska Peninsula that extends three degrees of latitude south of the southern limit of the Bristol Bay population.

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doi: dx.doi.org/10.7755/MFR.77.1.2

If the Cook Inlet population goes extinct, it is highly unlikely that Cook Inlet would be repopulated with beluga whales in the foreseeable future; the result would be a permanent loss of range.

Until 1999, Cook Inlet beluga whales were subject to an unregulated subsistence hunt (Mahoney and Shelden, 2000). Following abundance estimates that indicated this stock had declined nearly 50% (from 1994 to 1998), the National Marine Fisheries Service (NMFS) designated the stock as depleted under the U.S. Marine Mammal Protection Act (NOAA, 2000a). During this period of decline, beluga whales taken during the annual hunt ranged in number from 21 to 147 per year (Mahoney and Shelden, 2000), averaging about 70 whales per year killed and struck but not recovered. In 1999, the hunt was suspended and thereafter NMFS co-managed the hunt through a series of agreements with the Native hunting community (NOAA, 2000b).

Considering how few whales (only 5) were killed in the subsistence hunt in the 13 years between 1999 and 2012, wildlife managers anticipated that the population would begin to recover. However, the population showed no signs of recovery; accordingly, NMFS determined that the Cook Inlet beluga whale distinct population segment (DPS) was endangered as defined by the U.S. Endangered Species Act (ESA) (NOAA, 2008).

The abundance estimates noted above were generated from data collected by NMFS personnel from the Alaska Fisheries Science Center's National Marine Mammal Laboratory and Alaska Regional Office. NMFS conducts annual aerial surveys to study beluga whale distribution and abundance in Cook Inlet, Alaska. These surveys typically occur in June and have been repeated each year since 1993 (Rugh et al., 2000; 2005; Shelden et al., 2013). Abundance estimates from 1994 to 2000 were published in Hobbs et al. (2000a,b). This paper revisits that time period and presents changes in methods and statistical analyses that have occurred since 2000. The objectives of this paper include a reanalysis of the abundance estimates over the 19-year aerial survey time series (1994–2012), revising the population trajectory through 2012, and estimating population trend rates for endangered Cook Inlet beluga whales.

Methods

Aerial Surveys

Aerial surveys were designed to take advantage of the highly aggregated population of belugas seen near river mouths and relatively good weather and visibility in June and July.[1] Dur-

[1]Only in 1995, which occurred in late July. During this survey, whales were far more dispersed throughout the inlet than in June, affecting our

ing the summers of 1994–2012, flights took place during a 1- (1994–2003) to 2-week (2004–2012) period for 40–60 flight-hours each year. Surveys were flown at 800 ft (244 m) altitude at about 100 kn (185 km/h).

Survey protocol involved systematic searches of all coastal areas (within 3 km of the waterline) around Cook Inlet (1,350 km), where virtually all belugas are found during these months, as well as flying 500 to 1,500 km of sawtooth transects across the middle of the inlet (1994–2000 and 2011–2012) or north–south mid-inlet transects (2001–2010) to search for whales beyond 3 km from shore (Rugh et al., 2000, 2005; Shelden et al., 2013; Fig. 1). Mid-inlet and sawtooth transects followed a line transect survey design with distance to sighted marine mammals measured using hand held inclinometers.

The shoreline surveys did not meet the assumptions of line transect surveys because beluga groups are generally associated with geographic features such as river mouths and shallow tidal areas and thus are not randomly distributed either along the trackline or across the survey strip. Consequently, the intent of each survey flight was to find and count all beluga whales within Cook Inlet in the nearshore strata and estimate the density of whales in offshore areas (>3 km from shore). When whales were found, multiple aerial passes were made near whale groups until each observer had at least four good counts, and at the same time a videographer collected wide-angle and zoomed-in video recordings of the group.

The twin-engine survey aircraft had high wings, bubble windows, and more than 8 h endurance (an Aero Commander[2] 680/690 in most years, or a Twin Otter in two years). Observers were positioned on the left and right side of the aircraft directly behind the pilots. An additional observer sat behind the observer on the coastal side of the aircraft where almost all sightings of beluga whales occurred. A data recorder occupied the seat behind the observer viewing the offshore waters. The data recorder used custom software on a laptop computer to enter sightings data (species, clinometer angle, and group size), environmental conditions (Beaufort Sea state, visibility, cloud cover, and glare), comments, and changes in effort (such as off-effort while circling and counting whales or during periods of poor or unacceptable visibility).

All entries were stamped with time and date (using the clock on the computer) and location (downloaded into the laptop from a portable Global Positioning System (GPS)). Visibility was assessed by observers and documented in five subjective categories

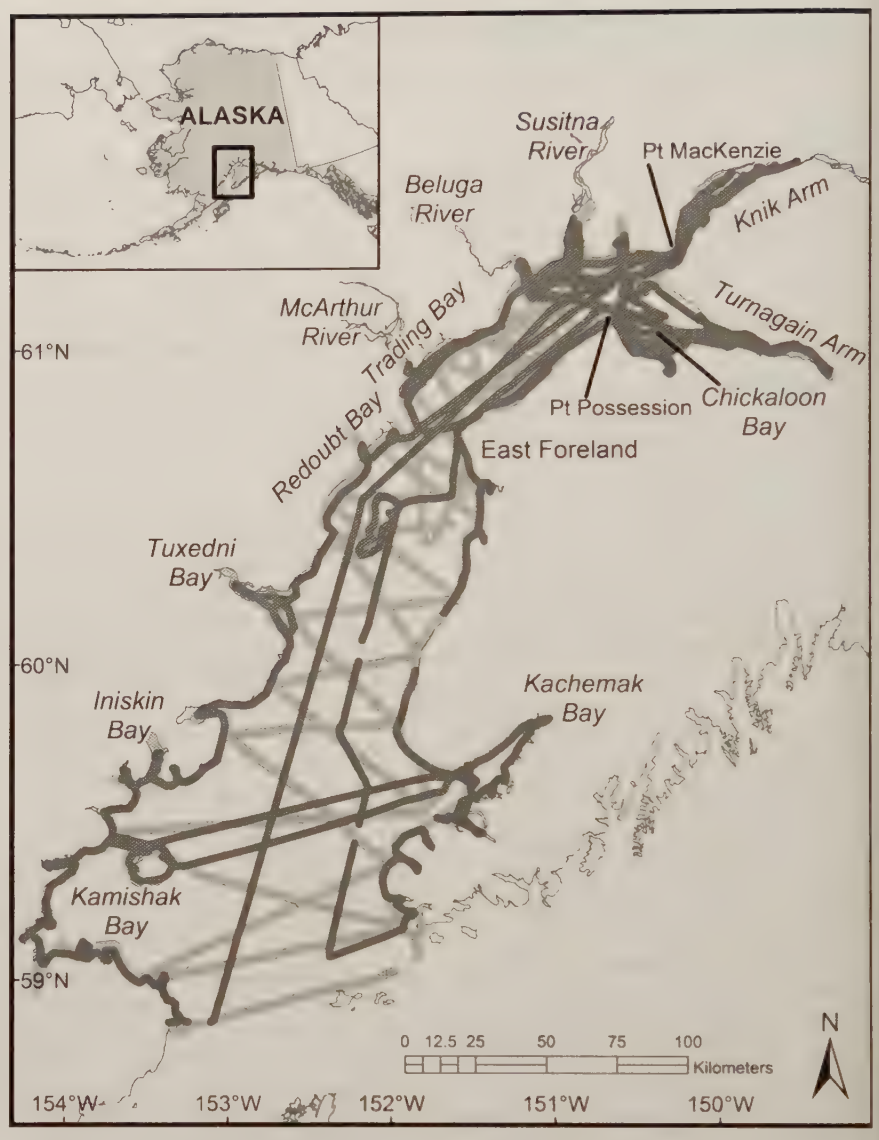

Figure 1.—Examples of survey tracklines from aerial counts of beluga whales in Cook Inlet, Alaska, 1994–2012. The light gray tracklines depict a "sawtooth transect" used to sample offshore waters 1994–2000 and 2011–2012. For 2001–2010, offshore tracklines roughly paralleled the coast (dark gray). See Rugh et al. (2000, 2005) and Shelden et al. (2013) for effort by year.

ability to find, count, and video groups. Thereafter, all abundance surveys were conducted in June.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA

from "excellent" to "useless." When visibility conditions were rated "poor" or "useless," the survey effort was not used in the analysis and the area was considered unsurveyed.

An intercom system provided communication among the observers, data recorder, and pilots, but when possible, a selective listening device was used to aurally isolate[3] the paired observer positions on the coastal side of the aircraft. This isolation setup allowed for independent search efforts, providing information on the probability of a single observer missing a whale group. Immediately upon seeing a whale group, each observer independently reported the sighting to the data recorder. After a whale group was reported, the trackline was maintained until the group was well behind the aircraft. The computer operator then turned off the isolation unit and changed effort status to "off" to end the transect leg before the plane circled back to begin counting passes.

Belugas were usually in distinct clusters, generally making it easy to define each group; however, when there were loose aggregations of whales, groups were defined for convenience of counting while circling over them. For example, whale groups within 100 m of each other were usually treated as a single group for counting purposes. Each whale group was circled using an extended oval around the group. Whale counts were made on each pass parallel to the long axis of the oval, with two observers and a videographer (the third observer) on the same side of the aircraft. The computer operator assigned a unique group identification number to each group, and recorded the start and end time of each counting pass as well as any comments made about group behavior, position of the plane, or issues with the video. The paired observers made independent counts until four to eight passes of at least good quality were obtained. Daily count records were not shared within the aerial team until the end of the survey season in order to maintain the independence of each observer's counts.

Paired video cameras were mounted side-by-side and used to record the beluga groups during the counting passes. One video camera was used for group counts, and it was set at a wide angle to view the entire group. The second video camera was used to determine correction factors for missed animals by zooming in to a narrower view to magnify individual whales in the group (Hobbs et al., 2000a). The analysis of the zoomed video recordings included the examination of color ratios, size, and proximity of white adults relative to dark juveniles and calves (Litzky, 2001; Hobbs et al., in press a).

Observer Counts

Annual aerial counts (serving as an index) represent the uncorrected tallies of whales made by observers during the aerial surveys (Rugh et al., 2000; 2005; Shelden et al., 2013). The annual index was calculated by reviewing all observer counts for a group and determining if counts should be combined or discarded based on the behavior of the beluga whale group. For example, when groups merged or split while counting passes were taking place, the changes were noted by the recorder.

During the nightly data review, the field project leader determined final group designations and checked that observer counts were assigned to the correct group or subgroup. Once a set of counts had been established for a group, a median value was calculated for each observer from counts that were given a grade of "A" or "B" (indicating that the location of the group was clearly visible to the observer and not affected by glare or whitecaps). Lower scores such as "C," "D," and "F" indicated that visibility was poor or part of the group was missed because it was too far from, close to, or under the plane, and were not used in the median calculation). A median value from all "A" or "B" observer medians was then calculated for each group. These group medians were summed by survey day and the largest of the daily sums was used as the index count for the year.

When group size could not be estimated for a beluga group from the video record, observer counts were used to estimate the group size. The estimation method, described in Hobbs et al. (2000a) and excerpted in the Appendix here, used group sizes estimated from video recordings as the dependent variable in a linear regression, with the observer counts and the observer counts multiplied by the encounter rate as the independent variables for those same groups. This method assumes that group sizes estimated from video recordings, and already corrected for availability bias (whales that were underwater and therefore not visible) and perception bias (whales are at the surface but not detected), represent the true group sizes. Therefore, the parameters fitted by the regression are an empirically derived correction factor that accounts for availability, perception, and observer differences.

We also found during the analysis for Hobbs et al. (2000a) that observers were under counting when groups were in large, dense aggregations. This required an additional correction to account for bias resulting from the time available to observers to count individual whales (Appendix; see also Video Counts section). These correction factors were then applied when video was not available (e.g., because of camera malfunction or poor quality video), to obtain group size estimates from observer counts alone.

Video Counts

Each video counting pass was reviewed for quality and rated on a scale (excellent, good, fair, poor, and unacceptable). Video passes rated excellent and good were analyzed using sequential transparencies or a computer-aided system (introduced in 2004). For the transparency method, a clear plastic transparency sheet (8 x 11 inches) was placed over the screen of a video monitor as the video tape was advanced frame by frame in a tape deck. At 0.5 second (15 frame) inter-

[3]In all years but 2011 and 2012.

vals each beluga image was marked in ink and the transparencies were compared in sequence to identify individual whale images and obtain a count of a group (Appendix).

With the introduction of digital video, a computer program was developed ("Beluga Dots") to capture and analyze the video sequences. With this program, analysts were able to catalog the individual whale images found in the survey video, track the images across the screen, and measure image size and color; all of these data were stored in a text file used by the program. The video analyst was able to review each video pass frame by frame or in slow motion and make changes to the corresponding saved data. After primary and secondary counts and zoomed analysis were completed, the program was used to export the saved data into a database format. This program increased efficiency and ease of reviewing the video, and a comparison of video counts made with plastic transparencies vs. the computer program found that the counts were equivalent.

The improvement of camera resolution over the 19 years of this project increased the likelihood that video analysts would detect small or darker whales in the counting video. The video collected from the zoomed camera each survey year made it possible to develop an appropriate correction factor (i.e., for whales missed at the surface in the counting video) for each year. While zoomed video quality has also improved with camera quality, in even the oldest zoomed video individual animal images were clear, and small, gray-colored belugas were easily distinguished from the background water color.

Abundance Estimation

The analysis methods applied to count data collected after 2000 and the resulting abundance estimates follow those presented in Hobbs et al. (2000a, b) (see Appendix), with a few notable exceptions below:

1) In the years 1994 to 2000, 4 years of data were averaged to estimate some correction factors (Hobbs et al., 2000b). Since then, only data collected during the respective survey season have been used to generate the correction factors for that specific season. The exception to this change in protocol was the continued use of data on whale surfacing intervals collected from suction cup tag data (Lerczak et al., 2000), which provided that same correction factor for the 19-year time series.

2) For estimations of abundance derived before 2001, the inlet was divided into three sectors: two for the upper inlet (northeast and northwest) and one for the lower inlet (all waters south of the Forelands)):

$$\hat{N}_{s,y} = \frac{\hat{K}_y}{J_{s,y}} \sum_{s=1}^{J_{s,y}} \sum_{i=1}^{G_{j,s,y}} \hat{n}_{i,j}$$

Where,

$\hat{N}_{s,y}$ is the estimated average abundance in sector s during year y,

$\hat{K}_y$ is the correction factor for belugas in groups that were missed in year y,

$J_{s,y}$ is the number of surveys conducted in sector s during year y,

$G_{j,s,y}$ is the number of groups seen in sector s during survey j in year y, and

$\hat{n}_{i,j}$ is the estimated number of whales in group i of survey j.

An average abundance was estimated for each sector (see Table 1 in Hobbs et al. (2000b)), and these estimates were summed for the overall abundance estimate (Hobbs et al., 2000b). Sectors on some survey days were excluded if estimates were unreliable (e.g., because of poor surveying conditions or incomplete coverage, or if estimates were below 60% of the highest estimate for the sector during the survey period).

From 2001 to 2003, the method of Hobbs et al. (2000b) was continued. Beginning in 2004, the number of survey days was increased and the northeast and northwest sectors in the upper inlet were combined so that the inlet was divided into two sectors (upper and lower). In years that belugas were not observed in the lower inlet, the formula could be further simplified, as each survey of the upper inlet captured the entire population:

$$\hat{N}_{j,y} = \sum_{i=1}^{G_{j,y}} \hat{n}_{i,j}, Var(\hat{N}_{j,y}) = \sum_{i=1}^{G_{j,y}} Var(\hat{n}_{i,j})$$

$$\hat{N}_y = \frac{\hat{K}_y}{J_y} \sum_{j=1}^{J_y} \hat{N}_{j,y},$$

$$Var(\hat{N}_y) = \frac{1}{J_y - 1} \sum_{j=1}^{J_y} (\hat{N}_y - \hat{K}_y \hat{N}_{j,y})^2 +$$

$$\frac{\hat{K}_y^2}{J_y^2} \sum_{j=1}^{J_y} Var(\hat{N}_{j,y}) + CV^2(\hat{K}_y)\hat{N}_y^2$$

Where,

$\hat{N}_{j,y}$ = the estimated number of beluga in groups found in survey j of year y,

$G_{j,y}$ = the number of groups found in survey j of year y,

$\hat{n}_{i,j}$ = the estimated number of beluga in the ith group found in survey j,

$\hat{N}_y$ = the estimated number of belugas in year y,

$\hat{K}_y$ = the multiplicative correction for belugas in groups that were missed, and

J_y = the number of usable surveys in year y.

Estimates from each survey day were summed, and only survey days with complete surveys of the upper inlet were used to estimate abundance in the upper inlet. This addressed the concern that groups of whales might move from one sector to another in the upper inlet between days during the two-week period of the surveys, but it required more survey days and flight hours to complete.

As previously, for survey days with unusually low estimates (e.g., less than about 60% of the highest daily estimate), the flight paths were reviewed to determine if a group seen on other survey days could have been missed either because the area was unavailable due to weather or air traffic or if the group could have moved to an adjacent area that was not surveyed. If this was the case, these survey days

were not included in the abundance estimate to reduce the possibility of biasing the estimate downward.

3) The estimate of the variance of the abundance in each sector equation in Hobbs et al. (2000b) under the heading Abundance Estimate was revised to use the squared standard error of the average for the sector in place of the variance of the abundance estimate and the measurement error. In Hobbs et al. (2000b), both measurement error and the standard deviation were included to avoid underestimation of the variance; at that time it was thought that there were significant variations in behavior from year to year that could not be corrected for with existing methods.

With the recent trend results, it is clear that the variance is overestimated by the method of Hobbs et al. (2000b). Examining the standard deviation of the residuals of abundance estimates from 1999 to 2012 around the trend line, we have an upper bound for the average CV of 11%. The residuals include both the variation resulting from the estimation (CV), and any variation in the dynamics of the population from year to year. Using the equation in Hobbs et al. (2000b), the average CV (square root of the mean of CV^2) for 1999–2012 was 17%, indicating that CV had been overestimated by this equation. The revised estimate of variance (shown below) accounts for the variation in behavior explicitly and uses the standard error which takes advantage of the increased sampling effort of the recent surveys.

Using the notation of Hobbs et al. (2000b), the variance is now:

$$Var(\hat{N}_{s,y}) = \frac{1}{(J_{s,y}-1)J_{s,y}} \sum_{j=1}^{J_{s,y}} \left(\hat{N}_{s,y} - \hat{K}_y \sum_{i=1}^{G_{j,s,y}} \hat{n}_{i,j} \right)^2 + \left(CV^2(T_{I,y}) + CV^2(\hat{K}_y) \right) \hat{N}^2_{s,y}$$

Where,

$\hat{N}_{s,y}$ = the estimated number of beluga whales in groups found in sector s (northwest, northeast, or south 1994–2003, and upper or lower 2004–2012) of year y,

$J_{s,y}$ = the number of surveys of sector s during year y.

$\hat{K}_y$ = the multiplicative correction for beluga whales in groups that are missed,

$G_{j,s,y}$ = the number of groups found in survey j of sector s of year y,

$\hat{n}_{i,j}$ = the estimated number of beluga whales in the ith group found in survey j,

CV = the coefficient of variation (standard error/mean) of an estimate (c.f. Hobbs et al., 2000b), and

$T_{I,y}$ = the annual mean of the average dive interval (time from the end of one dive to the end of the next) resulting from variation in average behavior of groups from year to year.

Revised Variance Estimates

For each year (1994–2012), the variance estimate for each sector was revised per the equation above, and the variance of the abundance by sectors was summed to estimate the variance of the totaled abundance as in Hobbs et al. (2000b). For areas with a single survey, typically the lower inlet, the measurement error was used. The value for $CV(T_{I,y})$ had not been estimated in the past. While considerable anecdotal data occur in the field reports (cf. Rugh et al., 2005; Shelden et al., 2013) regarding different beluga behaviors observed during the survey, no study has been conducted to relate these observations to variation in the average dive interval. As a proxy, we used time at surface data for a beluga captured and tagged in May 1999 with a satellite-linked time/depth recorder (SLTDR).

The SLTDR provided summaries of the amount of time that it was "dry" (when the dorsal ridge was above the water surface), summarized by 6-h intervals. Using the notation of Hobbs et al. (2000a) (see Appendix), the proportion of time that the transmitter was dry, P_{dry}, was proportional to T_s/T_I , where T_s was the average time at the surface per surfacing, and T_I was the average dive interval. In Cook Inlet, the whales were only visible when at the surface, thus T_s remained fairly constant and the variation in P_{dry} resulted largely from variation in T_I. Consequently, T_I was proportional to T_s/P_{dry}, and via the delta method (c.f. Seber, 1973), an estimate of $CV(T_I)$ was $CV(P_{dry})$.

To estimate the $CV(T_{I,y})$ for a survey period, we considered each set of 8 consecutive days (the average length of an aerial survey) for the twelve day period between the earliest start date of a survey (31 May) and the latest start date (11 June), such that 31 May–7 June was one sample, 1–8 June was the next sample, etc., with the final sample as 11–18 June. For each of these periods, the 8-day average of P_{dry} for the hours between 0900 and 2100 was calculated. The estimate of $CV(T_{I,y})$ was obtained by dividing the standard deviation of the averages by the mean of the 8-day averages.

Trend Estimation

Trends were estimated using weighted linear regression of the natural logarithms of the abundance estimates with the weights being the squared inverse of the coefficients of variation of the estimates. We considered the end of the unregulated subsistence hunt in 1999 to be the point in the time series where change in Cook Inlet beluga whale population dynamics may have occurred. To examine the impact of a trend in $T_{I,y}$ with survey dates, we regressed the residuals of the trend analysis against the median date for each survey.

To assess whether the increase in the survey days and change in analysis from two sectors to one had affected the estimated trend, we divided each survey from 2004 to 2012 into two 1-week surveys and then analyzed each week as a separate sample using the northeast/northwest sector methodology of Hobbs et al. (2000b). The resulting two abundance estimates for each year were considered replicates equivalent to the survey results for 1994–2003. We evaluated the trend re-

sulting from the two weeks, averaged by year.

We also created a distribution of all potential trend results by analyzing all possible combinations of 1-week samples from each annual pair of estimates and then applying the trend analysis as described above. We then compared the distribution of possible trends that were calculated using the 1-week survey sample size and analysis to the confidence interval of the trend that was calculated using current survey effort and analysis.

Results and Discussion

The timing of the abundance surveys takes advantage of the changes in beluga behavior that occur by late May–early June (Shelden et al., in press). At that time, most whales gather into large groups near river mouths to feed on anadromous prey returning to spawn in natal rivers. In the past, these large groups began to disperse to other areas within the inlet by July and August (Rugh et al., 2000; Shelden et al., in press). Throughout each abundance survey, beluga whales were seen near the coast and within river mouths in all years (Fig. 2), and after 2000, nearly all of the sightings occurred in the northernmost portions of the inlet. Belugas were found in the Susitna delta region (defined as the area between Point MacKenzie and the Beluga River) throughout the survey time series (Fig. 3).

Whales were also seen in large numbers in Knik Arm from 1997 to 2003, with a few observations continuing until 2007, after which none were found in this region during the June surveys (Fig. 3). From 2004 to 2007, more whales were observed in the Chickaloon Bay–Turnagain Arm region, coincident with the lower numbers seen in Knik Arm (Fig. 3). Smaller numbers of belugas (group sizes ranging from 1 to 27 whales) have been observed in areas south of North Foreland and Point Possession (Fig. 4), but not consistently.

All observer and video counts of beluga whale groups collected during the abundance surveys from 1994 to 2012

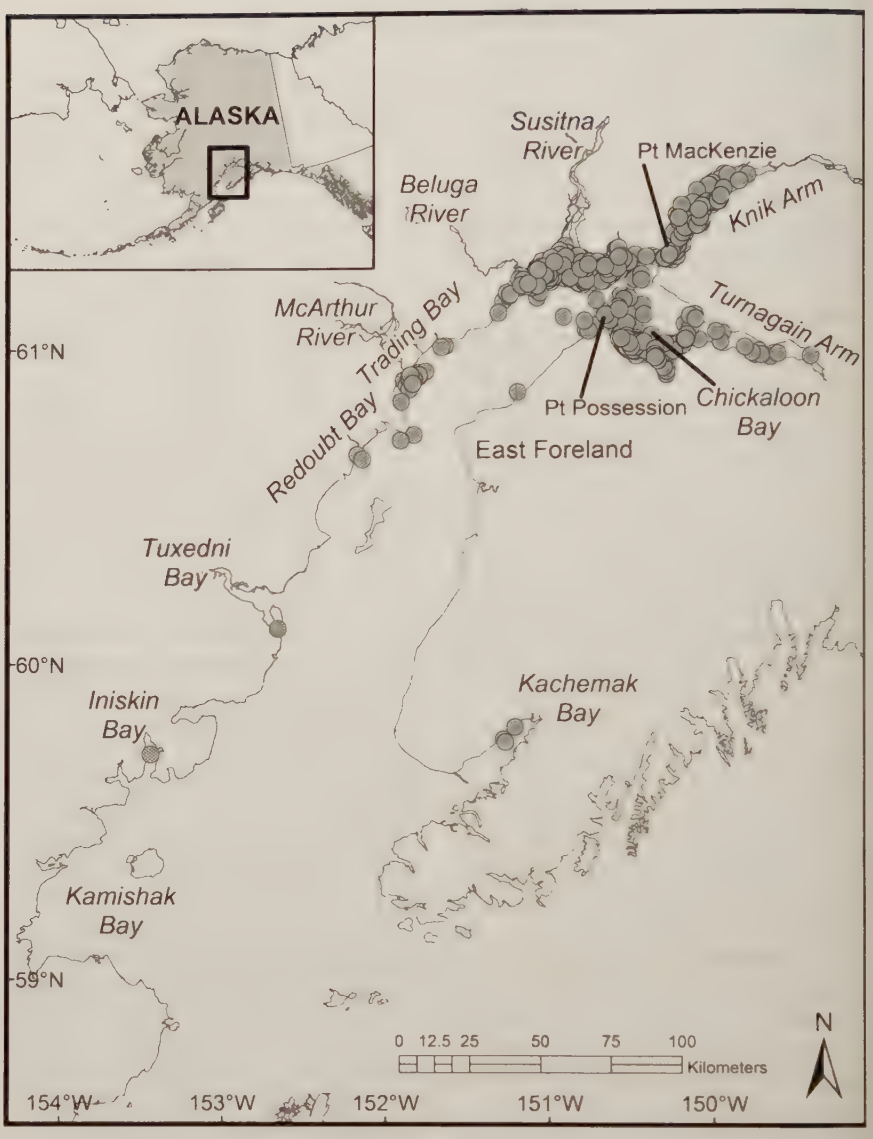

Figure 2.—Sightings of beluga whale groups in Cook Inlet, Alaska, made during aerial surveys, 1994–2012.

are presented in Table 1. Rounding errors were discovered for a few groups presented in the tables in Hobbs et al. (2000a, b) and have been corrected here. Index counts and abundance estimates for the 19-year time series are presented in Table 2.

For the 2001 to 2012 dataset, the average correction for whales missed below the surface (i.e., availability bias) in the video is 1.95 (SD = 0.42), while the average correction for whales missed at the surface (i.e., undetectable due to resolution of the video) is 1.31. This is similar to calculations from the 1994 to 2000 dataset where the average for these corrections was 2.03 and 1.17, respectively (Hobbs et al., 2000a). While improvements in video camera resolution did make a noticeable difference in the success rate of the video data collection from the period 1994–1998 (46% of estimates made from video) to the period 1999–2000 (84%, see Hobbs et al., 2000a), this was not as evident in the

Table 1.—Beluga whale groups reported during surveys of Cook Inlet, Alaska, 1994–2012, used to estimate abundance and/or corrections for missed groups. "Source" indicates whether group size was estimated from video analysis or by correction of counts from observers. "Estimated group size" is the corrected estimate for the respective group (from Hobbs et al., 2000a, b). CV = coefficient of variation. The last three columns indicate sighting records used in the logistic regression to estimate the probability that a beluga group might have been missed by the aerial observers: "Obs" is the ID number assigned to each observer (commas separate the first (i.e., front position) and second of the paired observers), "Vis" is the visibility (E = excellent, G = good, F = fair, P = poor, and U = useless) at the time of the sighting, and "Seen" indicates if the group was observed (1 = yes, 0 = no) and by which observer (first, second).

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
01 Jun 1994	1	4	Susitna R	1.12	1.22	209	17%	video	No			
01 Jun 1994	2	1	Susitna R	1.24	1.46	263	31%	video	No			
02 Jun 1994	1	4	W of Susitna R			394	60%	observer	Yes	3,2	G	1,1
02 Jun 1994	2	4	Turnagain Arm			18	47%	observer	Yes	3,2	G	1,1
02 Jun 1994	3	4	Chickaloon Bay			47	43%	observer	Yes	3,2	F	1,0
03 Jun 1994	1	5	Pt Possession			27	39%	observer	No	4,3	G	0,1
03 Jun 1994	2	5	Kachemak Bay			8	31%	observer	Yes	4,3	E	0,1
03 Jun 1994	3	3	Kachemak Bay			13	29%	observer	Yes			
04 Jun 1994	1	4	Iniskin Bay			4	30%	observer	Yes			
04 Jun 1994	2	4	W of Susitna R			144	31%	observer	Yes	3,1	G	0,1
04 Jun 1994	3	2	Susitna R	1.17	1.38	252	22%	video	Yes	3,1	G	1,1
04 Jun 1994	4	1	W of Little Susitna	1.14	3.39	475	24%	video	Yes	3,1	G	1,1
05 Jun 1994	1	3	Pt Possession/E Foreland			2	93%	observer	Yes	2,3	F	0,1
05 Jun 1994	2	1	Beluga R	1.16	2.21	41	51%	video	Yes	2,3	G	1,0
05 Jun 1994	3	1	W of Susitna R	1.16	1.08	20	96%	video	Yes	4,1	G	0,1
05 Jun 1994	4	6	W of Susitna R			21	34%	observer	Yes	4,1	G	0,1
05 Jun 1994	5	1	W of Susitna R	1.19	1.59	55	51%	video	Yes	4,1	G	1,1
05 Jun 1994	6	6	Little Susitna R			337	19%	observer	Yes	4,1	G	1,1
05 Jun 1994	7	1	Chickaloon Bay	1.16	1.52	11	110%	video	Yes	3,2	G	1,1
18 Jul 1995	1	5	Chickaloon Bay	1.26	1.36	29	36%	video	Yes	4,1	G	0,1
18 Jul 1995	2	8	McArthur R			1	115%	observer	Yes			
18 Jul 1995	3	7	Susitna R			731	36%	observer	Yes	1,3	G	1,1
19 Jul 1995	1	6	Chickaloon	1.16	1.42	20	41%	video	Yes	5,4	G	1,1
19 Jul 1995	2	5	McArthur R			8	58%	observer	Yes			
19 Jul 1995	3	1	Shirleyville			4	42%	observer	Yes			
19 Jul 1995	4	2	Susitna R	1.35	1.72	348	22%	video	Yes	4,5	E	1,1
20 Jul 1995	1	4	Chickaloon Bay	1.16	2.11	16	40%	video	No	1,5	E	1,1
20 Jul 1995	2	1	Susitna R	1.23	1	73	50%	video	Yes	1,5	E	1,1
20 Jul 1995	3	5	Susitna R			309	41%	observer	Yes			
21 Jul 1995	1	1	Susitna R (E)	1.16	1.55	32	65%	video	Yes	3,2	G	1,0
21 Jul 1995	2	5	Susitna R (W)			278	77%	observer	Yes	3,2	G	1,0
21 Jul 1995	3	1	Knik Arm			2	42%	observer	Yes			
21 Jul 1995	4	8	Chickaloon Bay			43	26%	observer	Yes	5,3	G	1,1
22 Jul 1995	1	4	Big R	1.16	1.75	17	42%	video	Yes			
24 Jul 1995	1	5	Drift R			5	105%	observer	No	3,4	F	1,0
24 Jul 1995	2	12	McArthur R			4	68%	observer	Yes	1,5	P	0,1
24 Jul 1995	3	1	Susitna R (W)	1.25	2.54	272	27%	video	Yes	1,5	G	1,1
24 Jul 1995	4	7	Susitna R (E)			94	45%	observer	Yes			
11 Jun 1996	1	1	S of Beluga R			2	42%	observer	No			
11 Jun 1996	2	6	Lewis R			13	69%	observer	No	1,4	G	1,0
11 Jun 1996	3	1	Ivan R			2	42%	observer	No			
11 Jun 1996	4	3	Theodore R			9	49%	observer	No			
11 Jun 1996	5	13	Lewis R			256	25%	observer	No			
12 Jun 1996	1	5	Knik Arm			12	39%	observer	No			
12 Jun 1996	2	1	Knik Arm			4	42%	observer	No			
12 Jun 1996	3	2	Susitna R (after stranding)	1.16	1.64	69	34%	video	No			
12 Jun 1996	4	1	Pt Possession			48	58%	observer	Yes	5,6	F	1,0
12 Jun 1996	5	12	Lewis R			304	29%	observer	No			
12 Jun 1996	6	9	Theodore R			12	39%	observer	No	6,4	G	1,1
12 Jun 1996	7	2	Lewis R	1.16	0.88	33	60%	video	No	6,4	G	1,1
12 Jun 1996	8	2	Susitna R			199	19%	observer	No	6,4	F	1,1
12 Jun 1996	9	5	Susitna R			47	29%	observer	No			
13 Jun 1996	1	7	Knik Arm			17	26%	observer	Yes	5,4	E	1,1
13 Jun 1996	2	7	Knik Arm			18	45%	observer	Yes	5,4	E	1,1
13 Jun 1996	3	3	Pt Possession	1.16	2.13	69	26%	video	Yes			
13 Jun 1996	4	8	Ivan R			168	20%	observer	Yes	6,1	G	1,1
13 Jun 1996	5	3	Susitna R	1.16	2.6	229	17%	video	Yes			
14 Jun 1996	1	6	Pt MacKenzie			39	39%	observer	No			
16 Jun 1996	1	6	Knik Arm			37	15%	observer	Yes			
16 Jun 1996	2	10	Knik Arm			28	32%	observer	Yes			
16 Jun 1996	3	2	Pt Possession	1.16	2.32	40	36%	video	Yes	1,4	E	1,1
16 Jun 1996	4	8	Lewis/Ivan R	1.12	3.08	365	9%	video	Yes	6,5	G	1,1
16 Jun 1996	5	4	Susitna R	1.16	1.75	69	23%	video	Yes	4,1	E	1,1
16 Jun 1996	6	8	Susitna/Little Susitna R			132	39%	observer	Yes	5,6	E	1,1
16 Jun 1996	7	2	Little Susitna	1.16	1.02	22	74%	video	Yes			
17 Jun 1996	1	2	Ivan/Susitna R	1.11	3.25	446	17%	video	No			
17 Jun 1996	3	3	Little Susitna R	1.15	1.19	30	44%	video	No			
17 Jun 1996	4	1	Ivan/Susitna R	1.16	3.06	230	28%	video	No			
08 Jun 1997	1	3	Knik Arm	1.1	2.14	30	34%	video	Yes			
08 Jun 1997	2	5	Knik Arm	1.29	1.41	63	23%	video	Yes	5,6	G	1,1
08 Jun 1997	3	5	Knik Arm	1.17	1.8	76	20%	video	Yes	1,7	E	1,1
08 Jun 1997	4	1	Knik Arm			2	42%	observer	Yes			
08 Jun 1997	5	5	Knik Arm	1.18	2.18	96	40%	video	Yes			
08 Jun 1997	7	1	Knik Arm			4	42%	observer	Yes			

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
08 Jun 1997	8	6	Chickaloon Bay	1.19	2.02	20	32%	video	Yes	6,5	G	0,1
08 Jun 1997	9	4	Chickaloon Bay	1.19	1.73	19	43%	video	Yes	6,5	G	1,1
08 Jun 1997	10	3	Susitna R	1.21	2.1	127	21%	video	Yes	7,1	G	1,1
09 Jun 1997	1	1	Tuxedni Bay			2	42%	observer	Yes			
09 Jun 1997	2	9	Susitna R			103	36%	observer	Yes	7,5	P	0,1
10 Jun 1997	1	4	Chickaloon Bay	1.14	3.3	113	16%	video	Yes	5,1	P	0,1
10 Jun 1997	2	15	Susitna R			140	35%	observer	Yes	6,7	G	1,1
10 Jun 1997	3	7	Knik Arm	1.14	2.15	153	12%	video	Yes			
10 Jun 1997	4	5	Knik Arm	1.18	2.03	60	21%	video	Yes			
10 Jun 1997	5	1	Knik Arm			2	42%	observer	Yes			
10 Jun 1997	6	2	Knik Arm			9	42%	observer	Yes			
09 Jun 1998	1	1	Little Susitna R	1.13	1.18	78	50%	video	No			
10 Jun 1998	1	8	Fire Island			21	52%	observer	Yes			
10 Jun 1998	2	5	Chickaloon Bay	1.16	1.62	27	33%	video	Yes	4,7	G	1,1
10 Jun 1998	3	3	Susitna R	1.23	1.45	139	23%	video	Yes	5,8	F	1,0
10 Jun 1998	4	1	Knik Arm			4	42%	observer	Yes			
10 Jun 1998	5	4	Knik Arm			21	39%	observer	Yes			
10 Jun 1998	6	4	Knik Arm			7	48%	observer	Yes			
10 Jun 1998	7	5	Knik Arm			8	41%	observer	Yes	7,4	G	1,1
10 Jun 1998	8	3	Knik Arm			64	42%	observer	Yes	8,5	F	1,1
10 Jun 1998	9	2	Knik Arm			9	50%	observer	Yes			
10 Jun 1998	10	5	Knik Arm			49	33%	observer	Yes			
12 Jun 1998	1	4	Little Susitna R	1.21	1.8	53	28%	video	Yes			
12 Jun 1998	2	5	Knik Arm			9	89%	observer	Yes	8,5	G	0,1
12 Jun 1998	3	2	Knik Arm	1.16	1.89	26	46%	video	Yes			
12 Jun 1998	4	3	Knik Arm	1.16	1.93	18	53%	video	Yes			
12 Jun 1998	5	3	Knik Arm	1.16	2.54	21	37%	video	Yes	4,8	G	0,1
12 Jun 1998	6	4	Knik Arm			19	66%	observer	Yes			
12 Jun 1998	7	1	Knik Arm	1.16	2.04	45	51%	video	Yes			
12 Jun 1998	8	3	Chickaloon Bay	1.16	1.74	31	40%	video	Yes	4,8	F	1,1
12 Jun 1998	9	2	Chickaloon Bay	1.15	1.16	19	68%	video	Yes	4,8	F	1,1
15 Jun 1998	1	3	Chickaloon Bay	1.18	2.34	89	22%	video	Yes	4,8	G	1,1
15 Jun 1998	2	1	Little Susitna R			2	42%	observer	Yes			
15 Jun 1998	3	4	Little Susitna R	1.21	1.79	285	14%	video	Yes	5,1	E	1,0
15 Jun 1998	4	3	Knik Arm			21	42%	observer	Yes			
15 Jun 1998	5	7	Knik Arm	1.16	2.13	40	21%	video	Yes	8,4	G	1,1
15 Jun 1998	6	2	Knik Arm	1.16	2.29	4	108%	video	Yes			
15 Jun 1998	7	5	Knik Arm	1.16	2.05	11	66%	video	Yes			
09 Jun 1999	1	6	Little Susitna R	1.08	2.62	314	17%	video	Yes	5,8	E	1,1
09 Jun 1999	2	3	Knik Arm			55	11%	observer	Yes			
09 Jun 1999	3	1	Chickaloon Bay	1.06	1.71	29	46%	video	Yes	4,1	E	
11 Jun 1999	1	1	Little Susitna R	1.06	3.21	245	41%	video	No	1,5;8,4	F,P	1,1;1,1
12 Jun 1999	1	4	Chickaloon Bay	1.19	2.62	3	44%	video	Yes	8,1	E	1,1
12 Jun 1999	2	6	Chickaloon Bay	1.14	1.63	30	19%	video	Yes	8,1	E	
12 Jun 1999	4	1	Beluga R	1.24	1.46	13	52%	video	Yes	4,5	E	0,1
12 Jun 1999	5	4	Susitna R	1.06	2.73	92	21%	video	Yes	4,5	E	0,1
12 Jun 1999	6	1	Little Susitna R	1.06	2.45	179	41%	video	Yes	1,8	E	1,1
12 Jun 1999	7	3	Knik Arm	1.20	1.69	39	26%	video	Yes	5,4	E	1,1
13 Jun 1999	1	2	Susitna R	1.15	1.42	25	33%	video	Yes	8,4	G	0,1
13 Jun 1999	2	4	Little Susitna R	1.13	1.46	258	21%	video	Yes	8,4	E	1,1
13 Jun 1999	4	5	Knik Arm	1.15	1.35	18	23%	video	Yes	4,8	G	
07 Jun 2000	1	3	Knik Arm	1.34	1.87	44	30%	video	No	1,8	E	1,0
07 Jun 2000	2	5	Knik Arm	1.18	2.28	25	22%	video	No			
08 Jun 2000	1	8	Little Susitna R	1.25	2.37	317	16%	video	Yes	1,4	E	1,1
08 Jun 2000	2	3	Little Susitna R	1.24	1.17	33	27%	video	Yes			
08 Jun 2000	3	2	Chickaloon Bay	1.11	3.32	11	38%	video	Yes	4,1	E	1,1
11 Jun 2000	1	9	Little Susitna R	1.15	2.37	231	15%	video	No	5,1	E	1,1
11 Jun 2000	2	5	Beluga R	1.27	1.77	2	41%	video	No	4,8	E	1,0
12 Jun 2000	1	8	Chickaloon Bay	1.26	2.28	31	20%	video	Yes			
12 Jun 2000	2	5	Chickaloon Bay	1.13	2.86	11	25%	video	Yes			
12 Jun 2000	3	8	Little Susitna R	1.11	2.52	357	15%	video	Yes	5,4	E	1,1
12 Jun 2000	4	1	Little Susitna R	1.08	3.61	27	47%	video	Yes			
12 Jun 2000	5	2	Knik Arm			13	79%	observer	Yes	5,4	G	1,1
12 Jun 2000	6	1	Knik Arm	1.16	3.00	3	74%	video	Yes	5,4	G	1,1
12 Jun 2000	7	5	Knik Arm	1.26	2.00	49	21%	video	Yes			
13 Jun 2000	1	2	Chickaloon Bay			9	51%	observer	No	1,4	G	1,1
13 Jun 2000	2	6	Susitna R	1.31	2.40	156	18%	video	No	1,4	E	1,1
13 Jun 2000	3	2	Knik Arm			18	32%	observer	No	5,8	E	1,1
13 Jun 2000	4	1	Knik Arm			9	68%	observer	No	5,8	E	1,1
13 Jun 2000	5	5	Knik Arm	1.14	2.88	28	22%	video	No			
05 Jun 2001	1	5	Little Susitna R	1.53	1.66	68	15%	video	Yes	5,1	F	1,0
05 Jun 2001	2	1	Knik Arm			6	130%	observer	Yes	5,1	G	0,1
05 Jun 2001	3	1	Knik Arm			5	130%	observer	Yes	5,1	G	0,1
05 Jun 2001	4	6	Knik Arm	1.54	2.01	115	13%	video	Yes	5,1	G	0,1
05 Jun 2001	5	4	Knik Arm, Eagle R	1.45	2.04	166	16%	video	Yes	4,8	E	1,0
05 Jun 2001	6	5	Turnagain Arm			16	35%	observer	Yes	4,1	E	0,1
05 Jun 2001	7	4	Chickaloon Bay	1.87	1.91	23	20%	video	Yes	1,4	F	1,1
06 Jun 2001	1	15	Susitna R			113	20%	observer	Yes	4,8	F	1,1

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
06 Jun 2001	2	3	Knik Arm	1.82	1.59	24	22%	video	Yes	4,8	G	1,1
06 Jun 2001	3	7	Knik Arm	1.70	1.87	19	15%	video	Yes	4,8	G	1,0
06 Jun 2001	4	7	Knik Arm	1.64	1.99	64	13%	video	Yes	4,8	G	1,1
06 Jun 2001	5	5	Knik Arm	2.09	2.08	131	14%	video	Yes	4,8	G	1,1
06 Jun 2001	6	16	Chickaloon Bay			32	43%	observer	Yes		G	
07 Jun 2001	1+2	4	Little Susitna R	1.39	2.00	128	16%	video	Yes	8,5:8,5	E	1,1:0,0
07 Jun 2001	3	8	Little Susitna R	1.94	1.92	80	12%	video	Yes	8,1	E	1,1
07 Jun 2001	4	1	Knik Arm			4	130%	observer	Yes	5,4	E	1,1
07 Jun 2001	5	5	Knik Arm	1.50	1.92	112	15%	video	Yes	5,4	G	1,1
07 Jun 2001	6	7	Knik Arm	1.49	2.11	37	14%	video	Yes	5,8	E	1,1
07 Jun 2001	7	6	Chickaloon Bay			7	36%	observer	No	1,4	F	1,1
08 Jun 2001	1	1	Kachemak Bay			2	0%	observer	No		F	
10 Jun 2001	1	6	Chickaloon Bay	1.85	1.74	45	14%	video	Yes	1,8	E	1,1
10 Jun 2001	2	6	Little Susitna R	1.57	1.75	263	13%	video	Yes	5,4	E	1,1
10 Jun 2001	3	6	Little Susitna R	1.71	1.40	18	17%	video	Yes		E	
10 Jun 2001	4	6	Knik Arm, Eagle R	1.86	1.82	50	14%	video	Yes	1,5	G	1,1
10 Jun 2001	5	6	Knik Arm, Eagle R	1.31	1.84	53	14%	video	Yes	1,5	G	1,1
10 Jun 2001	6	2	Knik Arm	6.25	1.52	4	48%	video	Yes		G	
11 Jun 2001	1	1	Potters Marsh	1.49	2.75	22	39%	video	Yes	5,4:4,5	G	1,0:1,1
11 Jun 2001	2	6	Chickaloon Bay	1.93	1.64	27	16%	video	Yes	5,4:1,8	F	1,1:1,0
11 Jun 2001	3	4	Susitna R	1.91	2.04	135	16%	video	No	8,1:1,8	G	1,1:1,1
11 Jun 2001	4	6	Pt MacKenzie			21	30%	observer	No		E	
11 Jun 2001	5	3	Knik Arm			8	58%	observer	No	1,8	E	1,1
11 Jun 2001	6	3	Knik Arm, Eagle R	1.63	1.99	8	30%	video	No	1,8	E	1,1
11 Jun 2001	7	2	Knik Arm, E side			4	8%	observer	No	1,5	E	1,1
12 Jun 2001	1a	9	Susitna R			25	40%	observer	Yes	5,8	F	1,1
12 Jun 2001	1b	25	Susitna R			131	23%	observer	Yes		F	
12 Jun 2001	2	6	Susitna R			11	35%	observer	Yes		F	
12 Jun 2001	4	1	Pt MacKenzie			11	130%	observer	Yes		F	
12 Jun 2001	5	10	Pt MacKenzie			14	71%	observer	Yes	5,8	G	1,1
12 Jun 2001	6	12	Knik Arm, Eagle R			3	96%	observer	Yes	5,8	E	1,1
12 Jun 2001	7	16	Knik Arm, Eagle R			34	53%	observer	Yes	1,5	E	1,1
05 Jun 2002	1	1	Pt Possession			3	0%	observer	No	8,9	G	1,1
06 Jun 2002	1	3	Knik Arm, Eagle R	1.19	2.48	159	17%	video	No	8,4	G	1,1
06 Jun 2002	2	2	Chickaloon Bay	1.16	1.63	26	25%	video	Yes	8,4	F	1,1
07 Jun 2002	1	1	Chickaloon Bay			16	5%	observer	Yes	1,4	E	1,1
07 Jun 2002	2	12	Knik Arm			105	21%	observer	Yes	8,9	E	1,1
07 Jun 2002	3	10	Knik Arm	1.09	2.25	13	40%	observer	Yes		E	
07 Jun 2002	4	8	Knik Arm	1.19	1.79	30	53%	observer	Yes		E	
07 Jun 2002	5	9	Knik Arm	1.14	2.05	18	59%	observer	Yes		E	
07 Jun 2002	6	1	Knik Arm			4	6%	observer	Yes	8,9	E	1,1
07 Jun 2002	7	6	Knik Arm			43	47%	observer	Yes		E	
07 Jun 2002	8	3	Knik Arm	1.25	1.92	17	23%	video	Yes		E	
07 Jun 2002	9	8	Chickaloon Bay	1.24	1.22	7	19%	video	Yes	1,4	G	1,1
07 Jun 2002	10	1	Chickaloon Bay			4	6%	observer	Yes	1,4	F	1,0
08 Jun 2002	1a+1b	2	Pt MacKenzie			10	23%	observer	No	8,9:8,9	E	1,0:0,1
08 Jun 2002	2	4	Pt MacKenzie			16	109%	observer	No	8,9	E	1,1
08 Jun 2002	3	12	Knik Arm, Eagle Bay			60	47%	observer	No	8,9	E	1,1
08 Jun 2002	4	9	Knik Arm, Eagle Bay			28	32%	observer	No	8,9	E	1,1
08 Jun 2002	5	7	Knik Arm			10	51%	observer	No	8,4	E	1,1
09 Jun 2002	1	16	Knik Arm			48	34%	observer	No	1,4	E	1,1
09 Jun 2002	2	6	Knik Arm			30	46%	observer	No	1,4	E	1,1
09 Jun 2002	3	6	Knik Arm			22	45%	observer	No	1,4	E	1,1
09 Jun 2002	4	17	Knik Arm			23	45%	observer	No	1,4	E	1,1
10 Jun 2002	1	6	Beluga R	1.17	1.65	7	22%	video	No	1,9	E	1,1
10 Jun 2002	2	2	Susitna R	1.29	1.71	30	25%	video	No	8,9	E	1,1
10 Jun 2002	4	7	Knik Arm, Goose Bay	1.16	1.64	12	17%	video	No	1,4	E	1,0
10 Jun 2002	5	4	Knik Arm, Eklutna	1.31	1.95	12	22%	video	No	8,9	E	1,1
10 Jun 2002	6	9	Knik Arm, Eklutna	1.18	1.84	5	107%	observer	No	1,4	E	1,1
10 Jun 2002	7	3	Knik Arm	1.18	1.85	45	19%	video	No	1,4	E	1,1
10 Jun 2002	8	15	Knik Arm, Eagle Bay			7	76%	observer	No		E	
11 Jun 2002	1	1	Chickaloon Bay			3	6%	observer	No	8,9	F	1,1
11 Jun 2002	2	11	Susitna R	1.25	1.33	135	38%	observer	Yes	8,9	F	1,1
11 Jun 2002	3	2	Knik Arm			2	20%	observer	Yes	1,4	E	1,1
11 Jun 2002	4	5	Knik Arm	1.16	1.68	130	13%	video	Yes	1,4	G	1,1
03 Jun 2003	1	6	Chickaloon Bay	1.06	1.97	112	14%	video	Yes	1,4	G	1,1
03 Jun 2003	2	8	Little Susitna R	1.05	3.06	33	14%	video	Yes	1,4	E	1,0
03 Jun 2003	3+4	6	Knik Arm, Eagle Bay	1.06	2.15	246	14%	video	Yes	1,4:1,4	G	1,0:1,1
04 Jun 2003	1	2	Chickaloon Bay			9	19%	observer	Yes	9,10	F	1,1
04 Jun 2003	2	3	Chickaloon R	1.08	2.69	59	21%	video	Yes		F	
04 Jun 2003	3	6	Knik Arm, Eagle R	1.06	2.29	13	52%	video	No	10,9	G	1,1
04 Jun 2003	4	1	Knik Arm, Eagle Bay	1.07	3.49	198	35%	video	No	10,9	G	1,1
05 Jun 2003	1	5	Potter Marsh	1.06	2.36	50	17%	video	No	1,4	E	1,0
05 Jun 2003	2	2	Chickaloon Bay			1	156%	observer	No	1,4	G	1,0
05 Jun 2003	3	2	Knik Arm, Eagle R	1.10	2.34	5	43%	video	No	1,4	G	1,1
06 Jun 2003	1	2	Chickaloon R, mouth	1.04	1.80	25	29%	video	Yes	1,10	G	1,1
06 Jun 2003	2	1	Chickaloon R, W of mouth	1.06	2.39	25	41%	video	Yes		G	
06 Jun 2003	3	8	Chickaloon R, bend			4	129%	observer	Yes		G	

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
06 Jun 2003	4	2	Beluga R			1	228%	observer	No	4,10	E	0,1
06 Jun 2003	5	3	Susitna R			2	227%	observer	No	4,10	G	0,1
06 Jun 2003	6	2	Little Susitna R	1.01	2.81	3	53%	video	No	4,10	G	1,0
06 Jun 2003	7	15	Knik Arm, Fish Creek			134	29%	observer	No	9,4	E	1,1
06 Jun 2003	8	7	Knik Arm, Palmer Slough	1.09	2.74	11	19%	video	No		E	
08 Jun 2003	1	3	Theodore R	1.06	2.59	11	28%	video	No	10,1	E	1,1
08 Jun 2003	2	8	Little Susitna R	1.07	3.21	65	13%	video	No	10,1	E	1,1
08 Jun 2003	3	2	Knik Arm, Goose Bay	1.04	3.09	6	40%	video	No	10,1	E	0,1
08 Jun 2003	4	6	Knik Arm	1.09	2.37	107	16%	video	No	10,1	E	1,1
08 Jun 2003	5	8	Chickaloon Bay	1.07	2.10	70	13%	video	Yes	1,10	G	1,1
10 Jun 2003	2	24	Beluga R			6	35%	observer	Yes	10,4	G	1,1
10 Jun 2003	3 (orig. 1)	6	S of Little Susitna R	1.08	3.08	28	16%	video	Yes	9,1(10,4)	E	1,0(1,1)
10 Jun 2003	4	8	Little Susitna R	1.02	3.55	36	14%	video	Yes	9,1	G	1,0
10 Jun 2003	5	10	Knik Arm			9	83%	observer	No	9,1	E	1,1
10 Jun 2003	6	4	Knik Arm	1.13	1.75	24	21%	video	No		G	
10 Jun 2003	7	2	Knik Arm	1.07	2.19	38	27%	video	No		G	
10 Jun 2003	8	2	Knik Arm, Birchwood	1.07	2.59	19	30%	video	No		G	
10 Jun 2003	9	2	Knik Arm, Eagle Bay	1.08	2.91	14	33%	video	No		G	
11 Jun 2003	1	2	Chickaloon Bay, E side	1.12	2.26	10	35%	video	Yes	9,1	G	
11 Jun 2003	2	3	Chickaloon Bay, W side	1.08	2.27	45	22%	video	Yes	9,1	E	
11 Jun 2003	3	2	Chickaloon Bay, W side	1.06	2.53	15	32%	video	Yes		E	
11 Jun 2003	4	3	Chickaloon Bay, W side	1.07	2.70	8	31%	video	Yes		E	
11 Jun 2003	5+6+7		Beluga R to Little Susitna R			not counted		observer	No	1,9	E	1,0:1,1:1,1
11 Jun 2003	8	1	Knik Arm, mid-arm	1.09	2.34	150	35%	video	Yes	1,9	E	1,1
11 Jun 2003	9	6	Knik Arm, south			20	58%	observer	Yes		G	
11 Jun 2003	10	1	Knik Arm, south			12	5%	observer	Yes		G	
02 Jun 2004	1		Little Susitna R			not counted		observer	No	1,4	G	1,1
03 Jun 2004	1	7	Little Susitna R			19	28%	observer	Yes	5,1	F	0,0
03 Jun 2004	2	1	Little Susitna R	1.17	2.39	424	47%	video	Yes	5,1	F	1,1
04 Jun 2004	1	6	Chickaloon Bay	1.27	2.45	22	36%	video	No	9,4	E	1,1
04 Jun 2004	2	7	Little Susitna R	1.33	2.04	123	29%	video	No	1,10	F	1,1
07 Jun 2004	1	4	Chickaloon Bay	1.41	2.35	253	33%	video	Yes	10,1	E	1,1
07 Jun 2004	2	7	Chickaloon Bay	1.23	2.09	73	30%	video	Yes		G	
07 Jun 2004	3	1	Susitna R	1.47	1.69	25	55%	video	Yes	1,4	G	1,0
08 Jun 2004	1	7	Little Susitna R	1.21	2.28	15	37%	video	Yes	9,5	G	0,1
08 Jun 2004	3	5	Turnagain Arm	1.26	2.74	88	33%	video	Yes	1,10	E	1,1
08 Jun 2004	4	2	Chickaloon Bay	1.37	2.05	104	40%	video	Yes	1,10	G	1,1
08 Jun 2004	5	3	Chickaloon Bay			19	20%	observer	Yes		G	
08 Jun 2004	6	7	Chickaloon Bay			39	11%	observer	Yes		G	
08 Jun 2004	7 (orig. 2)	1	Chickaloon Bay	1.36	2.22	106	45%	video	Yes	5,9(1,10)	E	1,1(1,1)
09 Jun 2004	1	3	Little Susitna R	1.31	2.18	31	41%	video	Yes	10,1	G	0,1
09 Jun 2004	2	2	Little Susitna R	1.34	2.21	16	53%	video	Yes		G	1,1
09 Jun 2004	3	6	Turnagain Arm	1.26	2.82	99	36%	video	Yes		E	0,1
09 Jun 2004	4a+5	1	Chickaloon Bay	1.49	2.25	100	43%	video	Yes	10,1	E	1,1
09 Jun 2004	4b	10	Chickaloon R			15	21%	observer	Yes	10,1	E	1,1
31 May 2005	2	2	Chickaloon Bay	1.06	1.65	37	48%	video	Yes	4,9	E	1,1
31 May 2005	3	3	Ivan R	1.08	2.16	229	40%	video	Yes	11,1	G	1,1
31 May 2005	4+5	2	Little Susitna R	1.05	1.36	7	61%	video	Yes	9,11:9,11	E	1,1:1,0
01 Jun 2005	1	5	Chickaloon Bay	1.05	2.13	45	38%	video	Yes	11,4	E	1,1
01 Jun 2005	2	2	Ivan R	1.07	2.28	46	47%	video	Yes	9,1	G	1,0
01 Jun 2005	3	7	Ivan R	1.07	2.19	79	33%	video	Yes	9,1	G	1,0
01 Jun 2005	4	4	Susitna R			156	32%	observer	Yes	11,4	E	1,1
02 Jun 2005	1	1	N of Pt Possession			2	0%	observer	Yes	12,1	G	0,1
02 Jun 2005	2	3	Susitna R	1.07	1.94	211	40%	video	Yes	12,1	G	1,1
02 Jun 2005	3	1	Knik Arm, Goose Bay	1.08	1.64	7	71%	video	Yes	11,4	E	0,1
02 Jun 2005	4	2	Chickaloon Bay	1.05	1.91	20	51%	video	Yes	11,4	G	1,0
05 Jun 2005	1	4	Chickaloon Bay	1.06	1.87	33	41%	video	Yes	11,1	G	0,1
05 Jun 2005	2	5	Susitna R	1.10	1.71	205	35%	video	Yes	12,9	E	1,1
08 Jun 2005	1	1	Chickaloon Bay	1.09	1.90	66	55%	video	Yes	4,12	P	1,0
08 Jun 2005	2	1	Chickaloon R			3	0%	observer	Yes	4,12	P	0,1
08 Jun 2005	3	4	Chickaloon Bay			29	30%	observer	Yes	1,11	P	1,1
08 Jun 2005	4	2	Chickaloon Bay	1.05	2.23	26	49%	video	Yes	1,11	F	1,1
08 Jun 2005	5	1	Chickaloon Bay			3	0%	observer	Yes	1,11	F	1,1
08 Jun 2005	6	1	Fire Island, SW tip			9	69%	observer	Yes	4,12	E	1,1
08 Jun 2005	7	3	Fire Island, SW tip	1.07	2.68	43	43%	video	Yes		E	
08 Jun 2005	8	1	Fire Island, SW tip			5	0%	observer	Yes		E	
08 Jun 2005	9	5	Susitna R	1.08	1.94	29	39%	video	Yes	4,12	E	1,1
08 Jun 2005	10	3	Knik Arm, Goose Bay	1.06	2.06	20	46%	video	Yes	4,12	E	1,0
09 Jun 2005	1	4	Turnagain Arm	1.06	1.52	31	41%	video	Yes	11,4	F	1,1
09 Jun 2005	2	3	Chickaloon R	1.05	1.98	78	41%	video	Yes	11,4	F	1,1
09 Jun 2005	3	1	Chickaloon Bay	1.08	2.23	17	62%	video	Yes	11,4	F	1,1
09 Jun 2005	4	1	Fire Island, SW tip	1.04	2.10	55	55%	video	Yes	11,4	G	1,1
09 Jun 2005	5	1	Susitna R			1	0%	observer	Yes	11,4	G	1,1
09 Jun 2005	6	6	Susitna R	1.07	1.96	34	37%	video	Yes	11,4	G	1,1
09 Jun 2005	7	2	Susitna R			10	36%	observer	Yes		G	
09 Jun 2005	8	1	Susitna R			1	0%	observer	Yes		G	
09 Jun 2005	9	1	Susitna R			6	0%	observer	Yes		G	
09 Jun 2005	10	1	Susitna R			1	0%	observer	Yes		G	

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
09 Jun 2005	11	3	Knik Arm, Eagle Bay	1.06	2.27	69	41%	video	Yes	1,11	E	1,1
06 Jun 2006	1	5	Pt Possession			16	59%	observer	Yes	1,10	F	1,1
06 Jun 2006	2	3	Susitna R			6	173%	observer	Yes	1,10	E	1,0
06 Jun 2006	3	4	Little Susitna R			15	85%	observer	Yes	1,10	E	0,1
06 Jun 2006	4	4	Little Susitna R			36	22%	observer	Yes		E	
06 Jun 2006	5	5	Little Susitna R			155	33%	observer	Yes		G	
06 Jun 2006	6	4	Chickaloon Bay			16	57%	observer	Yes	10,4	G	1,1
06 Jun 2006	7	4	Chickaloon Bay			21	52%	observer	Yes	10,4	G	1,1
06 Jun 2006	8	4	Chickaloon Bay			7	72%	observer	Yes	10,4	F	1,1
06 Jun 2006	9	4	Chickaloon Bay			9	90%	observer	Yes		U	
06 Jun 2006	10	4	Chickaloon Bay			13	116%	observer	Yes		U	
06 Jun 2006	11	1	Pt Possession			2	0%	observer	Yes	10,4	F	1,0
07 Jun 2006	1	2	Chickaloon Bay	1.27	2.10	17	30%	video	No	11,13	E	1,1
07 Jun 2006	2	3	Chickaloon Bay	1.37	1.89	22	23%	video	No		E	
07 Jun 2006	3	3	Susitna R	1.44	2.03	22	28%	video	No	11,13	E	1,1
07 Jun 2006	4	5	Susitna R	1.33	1.73	26	20%	video	No		E	
07 Jun 2006	5	2	Susitna R	1.46	1.85	43	30%	video	No		E	
07 Jun 2006	6	3	Little Susitna R	1.33	1.83	12	35%	video	No	13,11	F	1,1
08 Jun 2006	1	5	Chickaloon Bay			5	53%	observer	No	9,1	G	1,1
08 Jun 2006	2	4	Chickaloon Bay			8	68%	observer	No	9,1	E	1,0
08 Jun 2006	3	4	Beluga R	1.28	2.02	43	20%	video	No	9,11	G	1,1
08 Jun 2006	4	3	Susitna R	1.32	2.07	29	27%	video	No		E	
08 Jun 2006	5	8	Susitna R			55	27%	observer	No	9,11	E	0,1
08 Jun 2006	6	4	Little Susitna R	1.27	2.10	13	25%	video	No	9,13	E	1,0
08 Jun 2006	7	1	Knik Arm	1.33	2.62	14	50%	video	No	9,13	G	1,1
10 Jun 2006	1	1	Pt Possession			1	0%	observer	Yes		F	
10 Jun 2006	2	1	Pt Possession			15	0%	observer	Yes		E	
11 Jun 2006	1	6	Chickaloon R	1.44	1.75	7	38%	video	Yes	13,1	G	1,1
11 Jun 2006	2	2	Chickaloon R	1.44	2.32	17	44%	video	Yes	13,1	E	0,1
11 Jun 2006	3	2	Pt Possession	1.14	2.05	12	35%	video	Yes	13,1	E	0,1
11 Jun 2006	4	7	Pt Possession	1.08	1.79	14	19%	video	Yes	13,1	E	1,1
11 Jun 2006	5	4	Beluga R	1.28	2.09	8	30%	video	Yes		G	
11 Jun 2006	6	4	Susitna R	1.16	2.29	181	20%	video	Yes	13,1	G	1,1
11 Jun 2006	7	3	Knik Arm	1.24	2.17	15	28%	video	Yes	11,1	E	0,1
12 Jun 2006	1	1	Susitna R	1.33	1.86	188	36%	video	Yes		G	
12 Jun 2006	2	4	Chickaloon Bay	1.28	1.91	36	21%	video	Yes	13,11	E	1,1
12 Jun 2006	3	1	Chickaloon Bay	1.25	1.69	34	41%	video	Yes	13,1	E	1,1
12 Jun 2006	4	2	Chickaloon Bay	1.42	1.67	50	26%	video	Yes		P	
14 Jun 2006	1	1	Chickaloon R			1	0%	observer	No	11,1	E	1,0
14 Jun 2006	2	3	Chickaloon Bay	1.29	2.15	21	26%	video	No	11,1	E	1,1
14 Jun 2006	3	1	Chickaloon Bay			1	0%	observer	No		E	
14 Jun 2006	4	3	Chickaloon Bay	1.25	2.04	6	36%	video	No		E	
14 Jun 2006	5	1	Chickaloon Bay	1.29	2.06	53	26%	video	No		E	
14 Jun 2006	6	1	Pt Possession			6	0%	observer	No	11,1	E	0,1
14 Jun 2006	7	4	Beluga R	1.30	1.92	163	18%	video	No	11,1	E	1,1
14 Jun 2006	8	5	Susitna R	1.16	2.17	43	17%	video	No	11,1	E	0,1
14 Jun 2006	9	3	Little Susitna R	1.35	1.86	31	22%	video	No	11,1	E	0,1
15 Jun 2006	1	5	Chickaloon R	1.12	2.16	12	21%	video	No	5,13	E	1,1
15 Jun 2006	2	3	Chickaloon Bay	1.26	2.15	15	28%	video	No		E	
15 Jun 2006	3	4	Beluga R	1.28	2.01	33	22%	video	No	5,13	G	1,1
15 Jun 2006	4	2	Susitna R	1.14	2.08	51	27%	video	No		E	
15 Jun 2006	5	5	Susitna R	1.06	1.55	74	18%	video	No		E	
09 Jun 2007	1	4	Knik Arm, Goose Bay	1.25	2.35	6	80%	video	Yes	4,14	G	0,1
09 Jun 2007	2	9	Knik Arm, Eagle Bay	1.23	2.17	35	64%	video	Yes	4,14	E	1,1
09 Jun 2007	3	16	Susitna R			94	35%	observer	Yes	11,1	E	1,1
09 Jun 2007	4	5	Susitna/Little Susitna R			3	132%	observer	Yes	11,1	G	1,1
09 Jun 2007	5	8	Little Susitna R			58	16%	observer	Yes	11,1	G	1,1
09 Jun 2007	6	3	Turnagain Arm	1.39	2.53	24	85%	video	Yes	11,14	E	1,1
09 Jun 2007	7	4	Turnagain Arm			97	18%	observer	Yes	11,1	G	1,1
09 Jun 2007	8	2	Chickaloon Bay	1.55	1.55	2	102%	video	Yes	14,1	E	1,1
09 Jun 2007	9	8	Chickaloon Bay			6	24%	observer	Yes	14,1	E	1,1
09 Jun 2007	10	8	Pt Possession			63	15%	observer	Yes		E	
10 Jun 2007	1	4	Fire Island	1.43	1.35	14	79%	video	Yes		E	
10 Jun 2007	2	3	Susitna R	1.51	1.46	84	84%	video	Yes	11,4	E	1,1
10 Jun 2007	3	1	Susitna/Little Susitna R	1.37	1.75	55	110%	video	Yes	14,1	E	1,1
10 Jun 2007	4	1	Little Susitna R	1.37	1.60	9	113%	video	Yes		E	
10 Jun 2007	5	4	Little Susitna R	1.45	1.95	54	78%	video	Yes	11,4	E	1,0
10 Jun 2007	6	2	Little Susitna R			1	0%	observer	Yes	11,4	E	1,1
10 Jun 2007	7	5	Knik Arm, Windy Pt	1.41	1.54	31	74%	video	Yes		G	
10 Jun 2007	8	1	Burnt Island			1	0%	observer	Yes	11,4	G	0,1
10 Jun 2007	9	1	Burnt Island			1	0%	observer	Yes		E	
10 Jun 2007	10	1	Chickaloon Bay	1.61	1.31	21	112%	video	Yes	11,4	G	0,1
10 Jun 2007	11	3	Chickaloon Bay	1.34	1.78	42	84%	video	Yes	11,4	E	0,1
11 Jun 2007	1	4	Turnagain Arm			1	8%	observer	Yes	4,14	E	0,1
11 Jun 2007	2	1	Chickaloon Bay	1.54	1.64	18	112%	video	Yes	4,14	E	1,1
11 Jun 2007	3	2	Chickaloon Bay			3	0%	observer	Yes	4,14	E	0,1
11 Jun 2007	4	3	Chickaloon Bay	1.41	1.91	35	84%	video	Yes	4,14	G	1,1
11 Jun 2007	5	6	Little Susitna R	1.51	1.48	54	71%	video	Yes	1,11	G	0,0

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
11 Jun 2007	6	5	Little Susitna R	1.50	1.53	223	74%	video	Yes	14,4	E	1,1
11 Jun 2007	7	6	Knik Arm, Windy Pt	1.40	1.82	40	71%	video	Yes	1,11	F	1,1
14 Jun 2007	1	12	Chickaloon Bay			6	33%	observer	Yes	14,9	G	1,1
14 Jun 2007	2	8	Chickaloon Bay			3	99%	observer	Yes		G	
14 Jun 2007	3	2	Chickaloon Bay bluffs	1.31	1.56	42	93%	video	Yes	14,9	E	1,1
14 Jun 2007	4	1	Beluga R	1.48	1.66	12	112%	video	Yes	14,9	G	1,1
14 Jun 2007	5	2	Susitna R, W tributary	1.47	1.79	57	93%	video	Yes	14,9	G	1,1
14 Jun 2007	6	3	Susitna R, E tributary	1.42	1.69	177	84%	video	Yes	11,1	G	1,1
14 Jun 2007	7	2	Little Susitna R	1.54	1.91	48	93%	video	Yes	11,1	E	1,1
14 Jun 2007	8	4	Little Susitna R	1.33	1.77	39	78%	video	Yes	14,9	G	1,1
14 Jun 2007	9	3	Little Susitna R			1	0%	observer	Yes	14,9	G	1,1
14 Jun 2007	10	9	Knik Arm, Fire Creek			1	153%	observer	Yes		E	
14 Jun 2007	11	2	Fire Island, NE tip			2	0%	observer	Yes		G	
15 Jun 2007	1	1	Turnagain Arm			1	0%	observer	No		G	
15 Jun 2007	2	3	Chickaloon R	1.39	1.70	9	86%	video	No	9,1	E	0,1
15 Jun 2007	3	5	Chickaloon Bluff	1.40	1.13	5	77%	video	No	9,1	E	1,1
15 Jun 2007	4	3	Chickaloon Bluff	1.45	1.54	15	85%	video	No		E	
15 Jun 2007	5	3	Beluga R	1.41	1.27	178	84%	video	No	9,1	E	1,1
15 Jun 2007	6	3	Susitna R, E tributary	1.42	1.57	17	85%	video	No	9,1	E	0,1
03 Jun 2008	1	4	Beluga R			41	21%	observer	No	11,5	G	1,1
03 Jun 2008	2	16	Little Susitna R			137	56%	observer	No	11,1:1:15	E	0,1:0,1
04 Jun 2008	1	6	Susitna R	1.38	1.78	383	33%	video	Yes	1,4	G	1,1
05 Jun 2008	1	5	Chickaloon R	1.34	1.21	40	38%	video	No	15,1	G	1,0
05 Jun 2008	2	3	Susitna R	1.29	1.48	77	41%	video	No		G	
06 Jun 2008	1	4	Chickaloon R	1.27	1.80	7	52%	video	Yes	1,15	G	1,1
06 Jun 2008	2	4	Lewis R			2	0%	observer	Yes	1,15	E	1,0
06 Jun 2008	3	3	Little Susitna R	1.28	1.64	387	39%	video	Yes		E	
07 Jun 2008	1	10	Chickaloon R (morning)			50	37%	observer	Yes	1,15:1,5	G	1,1:1,1
07 Jun 2008	2	2	Susitna R (morning)	1.20	2.06	313	43%	video	Yes		P	
07 Jun 2008	3	3	Chickaloon R (afternoon)	1.25	1.93	120	40%	video	Yes		F	
11 Jun 2008	1 4	10	Beluga R			24	19%	observer	No	1,15	G,G,E,G	1,1:1,0:0,1
12 Jun 2008	1	9	Beluga R	1.20	2.28	220	30%	video	Yes		F	
12 Jun 2008	2	5	Little Susitna R	1.28	1.87	64	36%	video	Yes	1,15	F	1,1
02 Jun 2009	1	5	Susitna R, W tributary	1.23	1.90	183	10%	video	Yes	1,10	G	1,0
02 Jun 2009	2	5	Susitna R, E tributary	1.19	1.93	90	10%	video	Yes	1,10	E	1,1
02 Jun 2009	3	2	Chickaloon Bay	1.13	1.90	10	30%	video	Yes	1,10	F	1,1
03 Jun 2009	1	7	Little Susitna R	1.23	1.61	248	8%	video	Yes	1,10	G	1,1
03 Jun 2009	2	4	Chickaloon R	1.16	1.81	19	17%	video	Yes		G	
03 Jun 2009	3	3	Chickaloon Bay bluffs	1.20	1.91	30	17%	video	Yes	5,1	G	1,1
04 Jun 2009	1	5	Susitna/Little Susitna R	1.25	1.52	87	10%	video	Yes		E	
04 Jun 2009	2	5	Little Susitna R, mouth	1.23	1.65	146	10%	video	Yes	10,5	E	1,1
04 Jun 2009	3	1	Chickaloon R			2	0%	observer	Yes	10,1	P	0,0
04 Jun 2009	4	2	Chickaloon Bay bluffs	1.16	1.79	39	19%	video	Yes	10,1	G	1,1
05 Jun 2009	1	4	Chickaloon R	1.16	1.73	30	14%	video	Yes	1,10	G	1,1
05 Jun 2009	2	3	Chickaloon Bay bluffs	1.13	1.90	11	23%	video	Yes	1,10	E	1,1
05 Jun 2009	3	18	Susitna R			99	6%	observer	Yes	5,10	F	1,1
05 Jun 2009	4	5	Little Susitna R	1.19	1.55	181	10%	video	Yes	5,10	G	1,1
09 Jun 2009	5	6	Little Susitna R	1.17	2.15	118	9%	video	Yes		F	
09 Jun 2009	6	4	Susitna R	1.26	1.55	14	19%	video	Yes		F	
09 Jun 2009	7	2	Theodore R	1.21	1.61	252	15%	video	Yes		F	
09 Jun 2009	8	9	Pt Possession			29	22%	observer	Yes		E	
01 Jun 2010	1	4	Fire Island, SW tip			9	52%	observer	No	15,10	G	1,1
01 Jun 2010	2	10	E of Chickaloon R			21	29%	observer	No	15,10	G	1,0
01 Jun 2010	3	4	Chickaloon R	1.05	1.99	51	16%	video	No		G	
01 Jun 2010	4	5	Chickaloon Bay bluffs			14	33%	observer	No	15,10	F	0,0
01 Jun 2010	5	14	E of Little Susitna R			129	36%	observer	No	15,10	F	1,1
02 Jun 2010	1	3	Chickaloon Bay	1.06	1.52	126	20%	video	Yes	15,10	G	1,1
02 Jun 2010	2	5	Susitna/Little Susitna R	1.02	2.41	200	22%	video	Yes	15,10	E	1,1
04 Jun 2010	1	1	Turnagain Arm			1	166%	observer	No	10,11	G	1,0
04 Jun 2010	2	3	Chickaloon R, mouth			21	23%	observer	No	10,11	G	1,1
04 Jun 2010	3	12	Chickaloon Bay bluffs			8	86%	observer	No	10,11	G	1,1
04 Jun 2010	4	1	Susitna R, E tributary			4	166%	observer	No		G	
04 Jun 2010	5	7	Susitna R, E tributary			99	29%	observer	No	15,11	E	1,1
08 Jun 2010	1	10	Turnagain Arm, Six Mile			5	66%	observer	Yes	15,1	F	1,1
08 Jun 2010	2	2	Chickaloon R to bluffs	1.05	1.98	32	15%	video	Yes		G	
08 Jun 2010	3	4	Beluga/Ivan R	1.09	2.15	74	13%	video	Yes	15,1	G	1,1
08 Jun 2010	4	2	Susitna R	1.02	2.50	171	14%	video	Yes	15,1	G	0,1
08 Jun 2010	5	1	Susitna R, E tributary	1.09	1.24	69	16%	video	Yes	15,1	G	1,1
09 Jun 2010	1	2	W. of Chickaloon R	1.05	1.63	16	12%	video	Yes	5,11	G	1,1
09 Jun 2010	2	1	Chickaloon Bay bluffs	1.07	1.21	5	15%	video	Yes	5,11	G	1,1
09 Jun 2010	3	3	Theodore/Lewis R	1.08	1.85	88	14%	video	Yes	5,11	E	1,1
09 Jun 2010	4	10	Susitna R, W tributary			5	100%	observer	Yes		E	
09 Jun 2010	5	14	Susitna R, E tributary			144	27%	observer	Yes	5,11	G	1,1
09 Jun 2010	6	12	Little Susitna R, mouth			22	24%	observer	Yes	5,11	G	1,1
09 Jun 2010	7	11	Little Susitna R, first bend			7	47%	observer	Yes		G	
10 Jun 2010	1	5	Fire Island, SW tip	1.05	2.27	20	14%	video	Yes	1,11	G	1,1
10 Jun 2010	2	3	Turnagain Arm, Gull Rock	1.04	1.78	3	13%	video	Yes	1,11	G	0,1
10 Jun 2010	3	1	Burnt Island, offshore			2	133%	observer	Yes		G	

Table continued

Table 1.—*Continued*

Date	Group ID	No. of counts averaged	Location	Correction for whales missed at the surface	Correction for sub-surface whales	Est. group size	CV (%)	Counting method	Used in abundance estimate	Obs	Vis	Seen
10 Jun 2010	4	14	W of Chickaloon R			26	27%	observer	Yes	1,11	G	1,1
10 Jun 2010	5	1	W of Chickaloon R			13	133%	observer	Yes		E	
10 Jun 2010	6	3	Pt Possession	1.03	2.41	11	17%	video	Yes	1,11	E	1,1
10 Jun 2010	7	5	Susitna R, W tributary	1.04	1.79	17	14%	video	Yes	1,11	E	1,0
10 Jun 2010	8	4	Susitna R, W tributary			6	86%	observer	Yes		E	
10 Jun 2010	9	8	Susitna R, E tributary			8	37%	observer	Yes	1,11	G	1,0
10 Jun 2010	10	4	Susitna/Little Susitna R	1.02	2.26	233	14%	video	Yes	1,11	E	1,1
10 Jun 2010	11	3	Susitna/Little Susitna R	1.02	2.42	8	48%	video	Yes	1,11	E	1,1
10 Jun 2010	12	8	Little Susitna R, first bend			8	32%	observer	Yes	1,11	E	1,0
31 May 2011	1	12	Chickaloon Bay bluffs			57	16%	observer	Yes	no isolation unit, used 2010 correction for 2011 data.		
31 May 2011	2	15	Little Susitna R, mouth			200	7%	observer	Yes			
01 Jun 2011	1	3	Chickaloon R, mouth	1.97	1.62	13	22%	video	Yes			
01 Jun 2011	2	3	Chickaloon Bay bluffs	1.98	1.17	4	36%	video	Yes			
01 Jun 2011	3	5	Susitna/Little Susitna R	1.89	1.33	271	10%	video	Yes			
02 Jun 2011	1	4	Chickaloon Bay bluffs	1.96	1.23	22	17%	video	Yes			
02 Jun 2011	2	1	Lewis R	1.85	1.66	49	27%	video	Yes			
02 Jun 2011	3	5	Susitna/Little Susitna R	1.90	1.43	155	11%	video	Yes			
03 Jun 2011	1a	8	Chickaloon Bay bluffs			4	14%	observer	Yes			
03 Jun 2011	1b	3	Chickaloon R, mouth	2.11	1.11	77	15%	video	Yes			
03 Jun 2011	2	1	Susitna R, E tributary	1.92	1.22	187	24%	video	Yes			
04 Jun 2011	1	1	Fire Island, SW tip			3	70%	observer	No			
04 Jun 2011	2	2	Chickaloon R, mouth	1.87	1.44	18	25%	video	No			
04 Jun 2011	3	11	Chickaloon Bay bluffs			4	14%	observer	No			
04 Jun 2011	4	18	Theodore R			68	6%	observer	No			
04 Jun 2011	5a	2	Little Susitna R			5	19%	observer	No			
04 Jun 2011	5b	1	Little Susitna R	1.80	1.29	76	26%	video	No			
05 Jun 2011	1	2	Chickaloon R, mouth	1.97	1.52	21	24%	video	Yes			
05 Jun 2011	2	2	Chickaloon Bay bluffs	1.85	1.37	23	23%	video	Yes			
05 Jun 2011	3	3	Susitna/Little Susitna R	1.92	1.61	295	13%	video	Yes			
08 Jun 2011	1	2	Chickaloon Bay, Burnt Island	1.39	1.84	6	36%	video	Yes			
08 Jun 2011	2	12	E of Chickaloon R			11	20%	observer	Yes			
08 Jun 2011	3	2	Chickaloon R, mouth			4	3%	observer	Yes			
08 Jun 2011	4	12	W of Chickaloon R			18	11%	observer	Yes			
08 Jun 2011	5	8	Chickaloon Bay bluffs			17	9%	observer	Yes			
08 Jun 2011	6	15	Beluga R to Susitna R			223	10%	observer	Yes			
09 Jun 2011	1		Chickaloon Bay			not counted		observer	No			
09 Jun 2011	2	1	Beluga R, mouth	1.81	2.09	60	27%	video	No			
09 Jun 2011	3	1	Theodore R			11	42%	observer	No			
09 Jun 2011	4		Ivan R to Susitna R			not counted		observer	No			
09 Jun 2011	5	1	Little Susitna R, mouth			4	3%	observer	No			
01 Jun 2012	1	1	Chickaloon Bay bluffs			1	0%	observer	No	15,14	E	1,1
01 Jun 2012	2	1	Pt Possession			1	0%	observer	No	2,10	E	1,1
01 Jun 2012	3	1	Susitna R			8	0%	observer	No	15,14	E	0,1
01 Jun 2012	4	5	Little Susitna R mouth	1.26	1.43	129	4%	video	No	15,14	E	1,1
01 Jun 2012	5	3	McArthur R	1.16	1.95	25	8%	video	No	14,2	G	1,1
02 Jun 2012	1	1	Potter Marsh			1	0%	observer	Yes	10,15	G	1,1
02 Jun 2012	2	1	Beluga Pt			1	0%	observer	Yes	10,15	G	1,1
02 Jun 2012	3	2	Chickaloon Bay bluffs	1.09	1.88	26	8%	video	Yes	10,15	G	1,1
02 Jun 2012	4	2	Granite Pt	1.07	2.07	29	7%	video	Yes	15.1	E	1,1
02 Jun 2012	5	7	Susitna R, E tributary	1.15	1.83	119	3%	video	Yes	10,15	G	1,1
02 Jun 2012	6	4	Little Susitna R mouth	1.25	1.89	143	4%	video	Yes	10,15	G	1,1
03 Jun 2012	1	3	McArthur R	1.16	1.77	23	9%	video	No	14,15	E	1,1
03 Jun 2012	2	1	Susitna R, E tributary			3	0%	observer	No	14,15	F	1,0
03 Jun 2012	3	3	Little Susitna R	1.22	1.95	209	4%	video	No	14,15	F	1,1
04 Jun 2012	1	8	Mid-Chickaloon Bay			22	9%	observer	Yes	14.2	G	1,1
04 Jun 2012	2	3	McArthur R	1.21	1.7	17	7%	video	Yes	2,14	G	1,1
04 Jun 2012	3	4	Susitna R	1.13	2.06	128	5%	video	Yes	10,14	G	1,1
04 Jun 2012	4	3	Little Susitna R	1.21	1.95	173	5%	video	Yes		G	
04 Jun 2012	5	1	W of Little Susitna R	1.17	1.96	67	13%	video	Yes		G	
05 Jun 2012	1	7	Chickaloon Bay bluffs			4	12%	observer	Yes	2,15	E	1,1
05 Jun 2012	2	2	McArthur R	1.22	1.48	14	13%	video	Yes	15,2	G	1,1
05 Jun 2012	3	7	W of Little Susitna R	1.21	1.5	263	3%	video	Yes	15,2	G	1,1
06 Jun 2012	1	6	Chickaloon Bay bluffs			14	6%	observer	No	2,15	G	1,1
06 Jun 2012	2	5	McArthur R			14	6%	observer	No	14,2	G	1,1
06 Jun 2012	3	1	Susitna R			84	5%	observer	No		F	
07 Jun 2012	1	3	Chickaloon R			1	47%	observer	Yes	14,2	G	1,0
07 Jun 2012	2	4	Chickaloon Bay bluffs			7	12%	observer	Yes		G	
07 Jun 2012	3	2	McArthur R	1.13	1.5	25	23%	video	Yes	14,2	E	1,1
07 Jun 2012	4	4	Lewis R	1.1	2.43	54	14%	video	Yes		G	
07 Jun 2012	5	3	W of Little Susitna R	1.15	2.25	154	14%	video	Yes	14,2	G	1,1

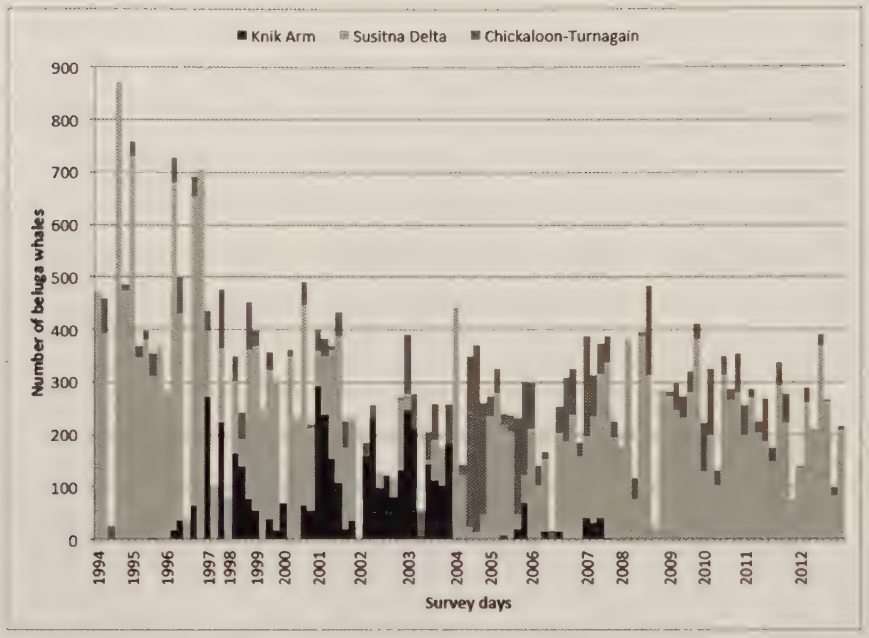

Figure 3.—Regions occupied by beluga whales in upper Cook Inlet, Alaska, north of North Foreland and Point Possession: Knik Arm, Chickaloon Bay–Turnagain Arm, and the Susitna delta (defined as the area between Beluga River and Point MacKenzie) from 1994 to 2012. Each survey day is represented as a single bar above and following the year indicated on the x-axis.

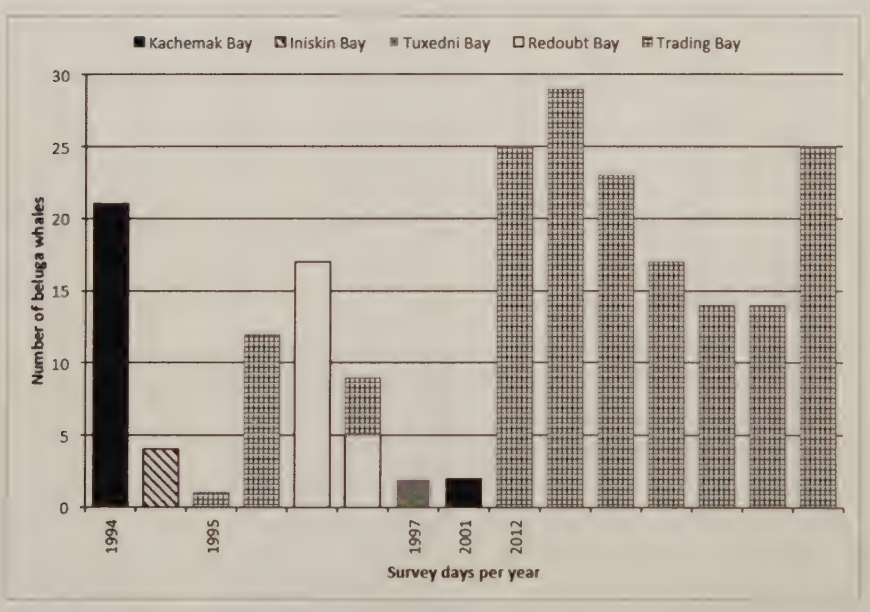

Figure 4.—Regions occupied by beluga whales in Cook Inlet, Alaska, south of North Foreland and Point Possession: Kachemak Bay, Iniskin Bay, Tuxedni Bay, Trading Bay, and Redoubt Bay, from 1994 to 2012. Each survey day is represented as a single bar above and following the year indicated on the x-axis.

2001–2012 dataset where 60% (range: 44–89%) of group size estimates were derived using video data (Table 1).

Analysis of the 6-h summarized time at surface data for the one whale tagged in 1999 indicated that the values for P_{dry} ranged from a low of 0.290 to a high of 0.350 with a mean of 0.306 (SD = 0.0193). Each field season represented a single draw from this distribution so that $CV(T_{I,y})$ is estimated to be 0.063. Regression of P_{dry} values against survey start date showed a significant relationship, with P_{dry} increasing by 0.0036 (SE 0.0013) per day, representing 36% of the variability in P_{dry}. This translates to a change in $T_{I,y}$ of 1.17% per day, suggesting that the progression from a 31 May to a 11 June survey start date corresponds with a change in beluga diving behavior, possibly related to prey switching from small smelt (eulachon, *Thaleichthys pacificus*) to adult salmonids (Chinook salmon, *Oncorhynchus tshawytscha*). While this trend does not affect the estimate of *CV*, it may have implications for the timing of the survey from year to year.

The revised estimates of variance yielded *CV* values that, in all cases, were less than those calculated by the equation of Hobbs et al. (2000b), and in some cases, were reduced nearly by half (Table 2). By explicitly accounting for the variation in beluga diving behavior (albeit from limited data, i.e., one tagged whale), it was possible to quantify an effect of behavior on abundance estimates that has been a point of speculation among observers. Regression of the residuals from the trend estimate against the median survey date of each survey resulted in a trend of 1.5% per day (SE = 1.4%), but it was not a significant relationship and explained less than 10% of the variability in the abundance estimates. While the trend over the survey period was a small part of the variability of $T_{I,y}$ from year to year, this highlights the need to consider variation in animal behavior when considering alternative survey start dates.

Estimates of abundance documented a decline of nearly 50% between 1994

Table 2.—Cook Inlet beluga whale aerial survey original and revised analysis results, June/July 1993–2012. The revised index counts use the highest daily count vs. the old index count that treated Turnagain Arm/Chickaloon Bay separately from the rest of upper Cook Inlet prior to 2003 (see Rugh et al. 2005:36). Abundance estimates based on sector analysis (the upper inlet divided into a northeast and northwest sector) for the years 2004 to 2012 include estimates for Week 1, Week 2, and an Average of the two weeks for comparison to previous survey years (1994–2003). The Old CV (coefficient of variation) was estimated using the method of Hobbs et al. (2000b). The revised CV is based on the standard error of the daily abundance estimates and an estimate of the variance based on diving behavior of a tagged whale. The trend estimates are for the years 1999 to 2012. The trend under Week 1 and Week 2 columns was the average of all possible combinations of the Week 1 and Week 2 estimates by year. The trends under Average and Abundance estimate (without sectors) included Week 1 estimates for the years 1999 to 2003.

Year	Survey date	Old index count	Revised index count	Abundance estimate (with sectors)			Abundance estimate (without sectors)	Old CV	Revised CV
				Week 1	Week 2	Average			
1993	June 2–5	305	302						
1994	June 1–5	281	276	653				0.43	0.24
1995	July 18–24	324	322	491				0.44	0.21
1996	June 11–17	307	287	594				0.28	0.20
1997	June 8–10	264	261	440				0.14	0.13
1998	June 9–15	193	192	347				0.29	0.17
1999	June 8–14	217	217	367				0.14	0.09
2000	June 6–13	184	184	435				0.23	0.14
2001	June 5–12	211	210	386				0.17	0.10
2002	June 4–11	192	181	313				0.12	0.10
2003	June 3–12		274	357				0.11	0.08
2004	June 2–9		187	477	356	417	366	0.20	0.13
2005	May 31–June 9		192	283	316	300	278	0.18	0.10
2006	June 5–15		153	276	311	294	305	0.15	0.10
2007	June 7–15		224	452	397	425	375	0.14	0.08
2008	June 3–12		126	459	292	376	375	0.23	0.11
2009	June 2–9		303	306	418	362	321	0.18	0.11
2010	June 1–9		291	284	347	316	340	0.11	0.08
2011	May 31–June 9		208	285	309	297	284	0.16	0.09
2012	May 29–June 7		319	317	301	310	312		0.13
Trend (1999–2012) as percent per year (Standard error)					-1.57% (0.42%)	-1.50% (0.86%)	-1.60% (0.75%)		

and 1998, from an estimate of 653 ($CV = 0.24$) whales to 347 ($CV = 0.17$) whales, respectively. This is a period during which subsistence whale hunts were unrestricted. The annual rate of decline during this time period was -13.7% (SE = 0.045). Abundance estimates since 1998 vary from as high as 435 ($CV = 0.14$) in 2000 to as low as 278 ($CV = 0.10$) in 2005 (Table 2, Fig. 5). With the very limited hunt between 1999 and 2012 (5 whales killed), it was anticipated that the population would begin to recover. However, the population continued to decline at a rate of -1.60% (SE = 0.75%) per year since 1999 (Fig. 5 trend line), with a 97% probability that the growth rate is declining (i.e., less than zero) and a 99.9% probability that the growth rate is less than +2% per year.

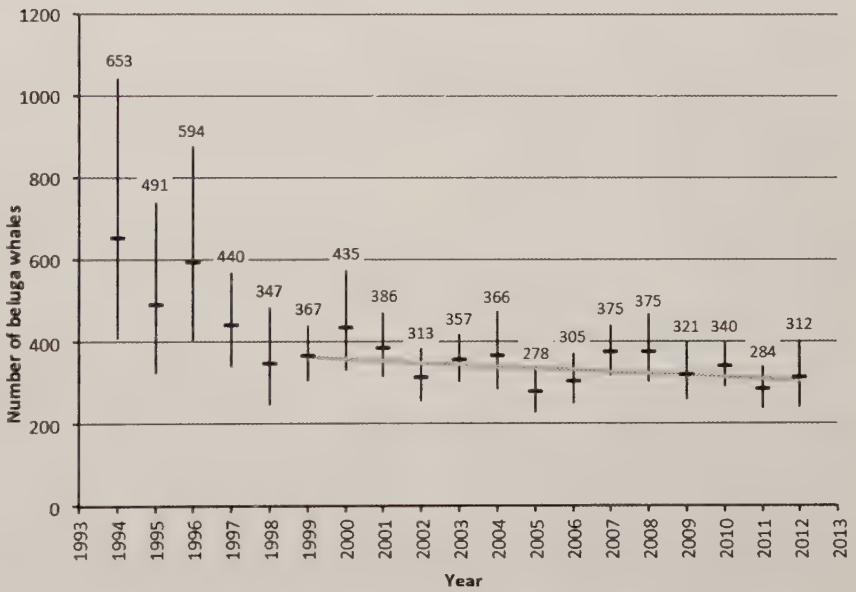

Figure 5.—Abundance estimates for beluga whales in Cook Inlet with 95% confidence intervals for revised coefficients of variation (CV's) (vertical bars). From 1994 to 1998, when the harvest was unrestricted, the annual rate of decline was -13.7% (SE = 0.045). In the years since a hunting quota has been in place (1999–2012), the rate of decline (trend line) was -1.6% (SE = 0.75%) per year.

Changes in survey methodology introduced in 2004 (i.e., increasing the number of survey days and no longer splitting the upper inlet into separate sectors) removed the concern that beluga groups moving between sectors (e.g., Fig. 3) could bias the estimate while not significantly affecting the trend results. Abundance estimates from each 1-week period (Table 2) were not significantly different from the estimate that included both weeks and did not split the upper inlet (n = 9 (2004–2012), T-$test = 2.12$; $p = 0.52$ (Week 1 vs. Abundance without sectors), $p = 0.61$ (Week 2 vs. Abundance without sectors), $p = 0.48$ (Weeks averaged vs. Abundance without sectors)).

Trend analysis using the "weeks averaged" estimates yielded an average annual rate of decline of -1.50% (SE

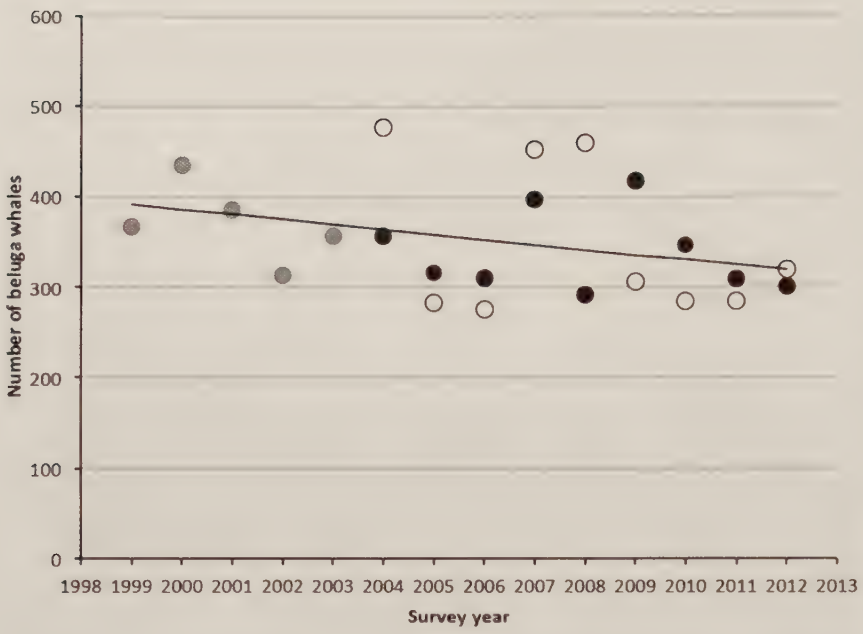

Figure 6. —Abundance estimates and trend for beluga whales in Cook Inlet during the hunting quota years (1999–2012) using analysis by week and sector. For 1999 to 2003, the existing estimates based on one-week surveys and sector analysis (c.f. Hobbs et al., 2000b) are presented as gray circles. For 2004 to 2012, the two-week surveys were divided into one-week surveys and sector analysis was applied to each week to obtain independent abundance estimates (shown as pairs of estimates for each year: week 1 = white circles, week 2 = black circles). The trend line was calculated from 1999 to 2012 (using the averaged abundance estimates for the years 2004 to 2012) and shows a growth rate of –1.50% per year.

= 0.86%) (Fig. 6). The possible trends when week 1 and week 2 were analyzed in all 512 possible combinations by year ranged from -2.56% to -0.56% with an average annual growth rate of -1.57% (Fig. 7). All of these trends fell within the 95% confidence interval of the current trend (-3.24%, +0.01%). Overall, the trend in growth remained negative regardless of the choice of weeks, averaging the weeks, or applying sector analysis.

Conclusions

With the distinctive geography of Cook Inlet and the affinity of beluga whales for specific locations, the survey design applied here covered all known prime beluga whale habitat several times as well as sampling areas where beluga whales are rarely seen. Relative to line transect survey techniques, these surveys of Cook Inlet are positively biased towards finding whales and, therefore, are not treated as random samples. The consistency of whale counts from day to day and year to year is a clear indication of the resolution of the sampling protocol; that is, these aerial surveys have a proven ability to find a high proportion of the beluga whale groups in Cook Inlet during each sampling period. Furthermore, counts have been remarkably repeatable between years with relatively small coefficients of variation, notable considering that this is a whale population being surveyed from an aircraft.

Collecting additional behavioral data will be key to further improvements in the precision of the abundance estimates, as the variability in the surfacing interval accounts for over half of the variation in the new *CV* estimates. With data from only one tagged beluga, without corresponding aerial observation, it is not possible to revise the abundance estimation procedure, only the estimate of variation. Results from tagging several animals in several years with corresponding aerial observations will be necessary to develop these correction methods.

Beluga whales in Cook Inlet have not shown appreciable signs of recovery since 1999 when hunting restrictions began. Although a significant decline in abundance was documented during the first 5 years of systematic abundance estimates conducted by NMFS from 1994 to 1998 (Hobbs et al., 2000b), there are few empirical data prior to this period except for a credible estimate of 1,300 beluga whales in Cook Inlet in 1979 (Calkins[4]). Between 1979 and 1994, there is insufficient information to model the apparent loss of half of this population from 1,300 to 650 beluga whales, which represents an average annual decline of around 5% (see Hobbs et al., in press b). However it suggests that the population was depleted in 1994 and is now at a depletion level of less than 25% of carrying capacity.

An Alaskan Native subsistence hunt (quantified through hunter interviews) was significant during the 1970's and 1980's and may have been at levels similar to the hunts reported in the mid-1990's (Huntington, 2000; Mahoney and Shelden, 2000). Also, commercial and sport hunts occurred during the 1960's and 1970's (Mahoney and Shelden, 2000). Therefore, the highest available abundance estimate of 1,300 may already represent a partially depleted population.

Compared to other cetacean species in U.S. waters, the Cook Inlet beluga is unique in the level of survey effort. A review of monitoring of marine mammal stocks in U.S. waters found only one other stock that was monitored on an annual basis (via a photo identification catalog) and no other

[4]Calkins, D. G. 1989. Status of belukha whales in Cook Inlet, *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information update meeting, 7-8 Feb. 1989, Anchorage , Alaska, p. 109–112. U.S. Dep. Inter., Minerals Manage. Serv., OCS Study, MMS 89-0041.

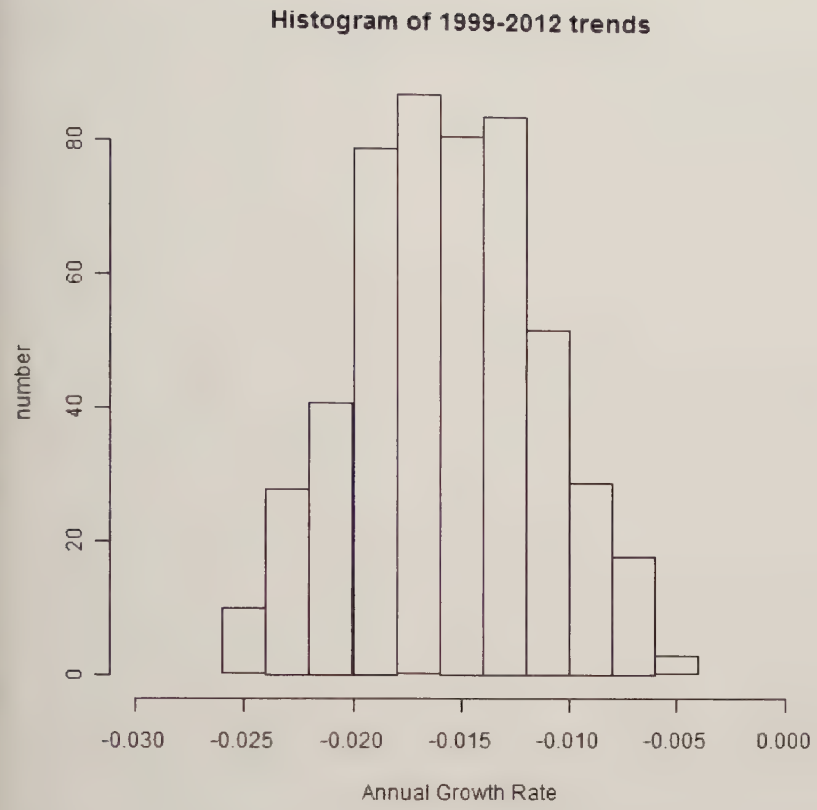

Figure 7. —Growth rate trends for Cook Inlet beluga whales based on abundance estimates from 1999 to 2012. For 1999 to 2003, the existing estimates based on one-week surveys and sector analysis (c.f. Hobbs et al., 2000b) were used. For 2004 to 2012, the two-week survey was divided into one-week surveys and sector analysis was applied to each week to obtain independent abundance estimates. All possible combinations (512) of one-week estimates were used to calculate a growth rate for each time series. These growth rate trends were rounded to the nearest 0.1%. The distribution of trends resulted in an average growth rate of –1.57% per year.

cetacean population with abundance estimates with *CV*'s consistently below 15% (Taylor et al., 2007). Thus, this 19-year time series of aerial surveys represents an outlier among the monitoring efforts of endangered cetaceans, but it has allowed us to demonstrate convincingly that the Cook Inlet stock continues to decline. The decline appears to be continuous and gradual suggesting that the population mechanisms involved are chronic decreases in fecundity and/or survival rather than a few unfortunate events of unusual mortality.

By 1999, there were sufficient data to indicate a clear decline in abundance of beluga whales in Cook Inlet, and in response, hunters instituted a moratorium on the hunt while NMFS and Congress moved to regulate the hunt. Although the rate of decline diminished from about 14% per year during 1994–1998 to <2% per year after the cessation of unregulated hunting in 1999, no satisfactory explanation is yet available for the continued decline. A similar lack of recovery has been noted in eastern tropical Pacific dolphins, *Stenella* sp. (Gerrodette and Forcada, 2005; Wade et al., 2007) as well as other odontocetes, leading to speculation that odontocetes in general may have difficulty recovering from over exploitation (Wade et al., 2012). However we must contrast this with the Bristol Bay population of belugas which is growing at an average rate of 4% per year after a period of depletion (Lowry et al., 2008). Further monitoring and research to investigate the mechanisms of decline will be required to determine the reason for the current decline of the Cook Inlet beluga and are critical to the management and recovery of this small, isolated population.

Acknowledgments

Funding for this project was provided to the NMFS Alaska Fisheries Science Center's (AFSC) National Marine Mammal Laboratory (NMML) by the NMFS Marine Mammal Assessment Program, as well as through funds and logistical support from the NMFS Alaska Regional Office. Aircraft and pilots were provided by Commander NW Ltd., NOAA's Aircraft Operations Center, Northern Commanders LLC, and Clearwater Air Inc. Aerial survey observers for this project, all NOAA employees or contractors, were R. Angliss, D. DeMaster, K. Goetz, J. Hanson, R. Hobbs, L. (Litzky) Hoberecht, J. Lewis, B. Mahoney, J. Mocklin, D. Rugh, T. Ruszkowski, K. Shelden, O. Shpak, C. Sims, B. Smith, S.Thumm, L. VateBrattström, J. Waite, and D. Withrow.

Laboratory assessment of the video was provided by L. Baraff, R. (Lowell) Bush, R. DeLeuw, K. Goetz, S. Harkness, L. (Litzky) Hoberecht, K. Lestyk, J. Mocklin, M. Muto, S. Norman, C. Rosevelt, D. Rugh, L. Santos, K. Shelden, C. Sims, L. VateBrattström, and J. Waite. Research surveys in Cook Inlet were conducted under NMFS Scientific Research Permits No. 791 (P771#63), 782–1360, 782–1438, 782–1719, and 14245. Document reviews were provided by P. Clapham (NMML), N. Friday (NMML), C. Baier (AFSC Publications Unit), and two anonymous reviewers.

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Appendix.—Correction factors applied to video and observer data to estimate group sizes during aerial abundance estimate surveys of Cook Inlet, Alaska, beluga whales (excerpted from Hobbs et al. (2000a:50–52).

Correction for Perception Bias

Detecting whales in video recordings is limited by the resolution of the video system. Probability of detection was measured by comparing the whales seen in the zoomed video to those seen in the corresponding region on the counting video. The whale images in the zoomed video were each assigned to one of three categories: 1) whales that were seen in both the zoomed and counting video; 2) whales in the zoomed video that were missed in the counting video due to proximity—two whales surfacing close to each other appear as one large image on the counting video; or 3) image size—a whale seen in the zoomed is too small or gray so that it falls below a threshold and does not form a visible image on the counting video. The two mechanisms (proximity and image size) that affect whale detection in the counting video require different approaches for correction.

Proximity Correction

When two whales were close enough together to appear as a single whale on the counting video, the space between them was much narrower than the width of an average whale. Consequently, these two images would be merged throughout the typical range of magnifications used in the counting video, regardless of their relative size. Thus, a constant ratio could be used to correct for whales missed due to proximity:

$$\frac{J_z}{J_z - J_p},$$

where J_z is the number of whales seen in the zoomed video and J_p is the number of whales missed due to proximity.

Image Size Correction

The resolution of a video system is limited by the density of scan lines in the video recording system and the density of pixels on the display moni-

tor. This process of scanning and pixelation has the effect of smearing images and edges by averaging the gray scale and hue across each pixel. If a pixel is half water and half beluga, then it will appear to have a gray scale and hue halfway between that of the water and the beluga. A large, white beluga will appear as a bright white ellipse with a fuzzy edge that fades to the gray scale of the water. A gray beluga will appear as a gray ellipse with a less distinct fading to the water color. Small, gray belugas or distant belugas of any hue may not have a sufficiently large image to completely fill any pixels so that the image is entirely made up of these averaged pixels. Because the edge of the image has been blurred, it is necessary to interpret by eye the margin of the image from the surrounding background. Experience has shown that with a limited amount of training, consistent and repeatable measurements of beluga images can be made. However, the measurement method is partially subjective, so it is necessary to estimate the bias in the interpreted image size. The smearing occurs only at the edges, so the bias should be independent of size. The gradient that is interpreted is dependent on the difference in hue between the object and the background. The subjectivity involves a determination of the point along this gradient that is the edge of the image.

The lengths of the images at the midtimes of beluga surfacings matched between the counting and zoomed videos can be related by the following formula:

$$\frac{L_z}{m} = \frac{l_z - b}{m} = l_c - b = L_c,$$

where L_z and L_c are the unbiased sizes of the whale images on the zoomed and counting videos, respectively; l_z and l_c are the measured sizes of the whale images on the zoomed and counting videos, respectively; m, is the relative magnification between the zoomed and counting video frames (obtained as the ratio of the distance between centers of two whale images seen on both the counting and zoomed video); and b is the bias resulting from smearing of the edge. An average value for the bias can be estimated from several image pairs as,

$$\hat{b} = \frac{\sum_{j=1}^{J_n}(l_{zj} - m_j l_{cj})}{\sum_{j=1}^{J_n}(1 - m_j)},$$

where J_n is the number of whales seen in both the zoomed and counting video, and j is the index of the jth pair. If b was not significantly different from zero, it was not necessary to correct for bias.

The following equation was then used to estimate the image size in the counting video for the whales that were visible in the zoomed video but, because of their size, were not detected in the counting video. The estimated image size for these whales in the counting video was:

$$\hat{l}_c = \frac{l_z - \hat{b}}{m} + \hat{b}.$$

A binomial logistic regression was applied to the resulting combined distribution of measured and estimated standard image sizes to estimate the probability that a whale with a given image size would be seen in the counting video.

For a given group, g, and pass, p, m is not known. Instead, the average of image sizes, $\mu_{g,p}$, and the fractions of whales that would be detected, $F(\mu_{g,p})$, in a counting video are related. To determine this relationship, arbitrary values for magnification, m' , (e.g., magnification increasing at 0.01 intervals) are chosen to span the range of possible magnifications. The combined distribution of observed (whales seen in both the zoomed and counting video) and estimated (whales seen in the zoomed but missed in the counting because of small size) counting video sizes are then re-scaled by

$$\hat{l}_{m'j} = (l_{cj} - \hat{b})m' + \hat{b}$$

to simulate the distribution of image sizes under these arbitrary magnifications. For this re-scaled distribution, the average of image sizes, $\mu(m')$, and the fractions of whales, $F(\mu(m'))$, that would be detected in a counting video are

$$\mu(m') = \frac{\sum_{J_n+J_w} P(\hat{l}_{m'j})\hat{l}_{m'j}}{\sum_{J_n+J_w} P(\hat{l}_{m'j})}$$

$$F(\mu(m')) = \frac{\sum_{J_n+J_w} P(\hat{l}_{m'j})}{J_n + J_w}$$

where $P(l)$ is the probability that an image of size l will be seen in the counting video. A lookup table relating average image size for a group counted from video, $\mu_{g,p}$, to the correction for the fraction that were missed because of image size, $1/F(\mu_{g,p})$, was created from this analysis. For passes with a sample of measured images, the fraction missed was found in the table. Passes of small groups where images were not measured were given the average fraction missed from other passes of the same group, or if no other passes on the group had measured images, the pass was given the average fraction missed of all measured passes from all groups.

Combined Correction Factor

The correction for perception bias was the product of the proximity correction and the image size correction. For a video count with an estimated average image size, $\hat{\mu}_{gp}$, the correction factor, $D_{g,p}$ is then,

$$D_{gp} = \left[\frac{J_z}{J_z - J_p}\right]\frac{1}{F(\mu(m'))}.$$

Correction for Availability

The formula of McLaren (1961) for the correction for availability bias is the inverse of the probability that a typical beluga is at or will appear at the surface during the videotaping. The correction factor, $A_{g,p}$, for a group and pass depending on the time spent counting, $t_{g,p}$, is calculated as,

$$A_{g,p} = \frac{T_I}{T_s + t_{g,p}},$$

where T_I is the average dive interval (24.1 sec., Lerczak et al., 2000), and T_S is the average time at the surface from the video analysis described above.

Estimation of Group Size

The group size, $\hat{n}_g$, was estimated by averaging the corrected video counts for a group:

$$\hat{n}_g = \frac{1}{P_g} \sum_{P_g} c_{g,p} D_{g,p} A_{g,p},$$

where, $c_{g,p}$ is the count for group g from pass p, and P_g is the number of passes for group g that were counted. When a video pass contained two or more distinctly different segments (e.g., it began using the point method, then switched to the scan method when the first portion of the group came abeam of the plane), the counts were corrected separately to create a group size estimate for each subgroup. These subgroup estimates were then summed to estimate the total group size.

The coefficient of variation (CV) for $\hat{n}_g$ was estimated as:

$$CV(\hat{n}_g) = \sqrt{\frac{\overline{CV}^2(n)}{P_g} + \overline{CV}^2(D_g) + \overline{CV}^2(A_g)}$$

An average CV for a group size estimate made from a single count was estimated by averaging the variation of the group size estimates of all groups where more than one pass from the group was counted from video(G_2),

$$\overline{CV}^2(n) = \frac{\sum_{G_2} \frac{1}{P_g - 1} \sum_{P_g} (n_{g,p} - \bar{n}_g)^2}{\sum_{G_2} \bar{n}_g^2}.$$

Where more than one count is used to estimate group size, this average CV is scaled appropriately. The value $CV(n)$ includes an empirical measure of stochastic variation between counts that is not corrected by the two correction factors, but it does not account for the variation of the correction factors themselves which must be accounted for separately.

The component of the CV resulting from the correction for perception, $CV(D_g)$, is estimated by the delta method as,

$$\overline{CV}^2(D_g) = \frac{\sum_{P_g} \left[\left. \frac{\partial D}{\partial \mu} \right|_{\mu_{g,p}} \right]^2 SE^2(\mu_{g,p})}{\left[\sum_{P_g} D_{g,p} \right]^2}.$$

For cases where $\mu_{g,p}$ was not estimated, the correction factor $D_{g,p}$ was derived from an average of $\mu_{g,p}$ from other passes of the same group or an average of other groups. In these cases $SE(\mu_{g,p})$ was the standard deviation of the set of the estimated average image sizes of the averaged groups.

The component of the CV resulting from the correction for availability, $CV(D_g)$, is dominated by the variation of T_I. The variation of T_I has a component related to the variability between individuals and the variation of a typical individual. Following the delta method yields,

$$\overline{CV}^2(A_g) = \frac{\sum_{P_g} \left[\frac{1}{T_S + t_{g,p}} SE_g(T_I) \right]^2}{\left[\sum_{P_g} A_{g,p} \right]^2} = \frac{\frac{\sigma_A^2 + \sigma_I^2}{\hat{n}_g} \sum_{P_g} \left[\frac{1}{T_S + t_{g,p}} \right]^2}{\left[\sum_{P_g} A_{g,p} \right]^2}$$

where σ^2_A (= 41 sec^2 , σ_A = 6.4 sec) and σ^2_I (= 707 sec^2 , σ_I = 26.6 sec) are the variance of the average dive interval among individuals and the average variance of the dive interval of individuals, respectively (values taken from Lerczak et al., 2000). Note that in this formulation, $CV(A)$ was not independent of group size because of the assumption that the dive behavior of individuals in the group is uncorrelated so that the variation in the average of dive intervals during the counting interval decreases as group size increases.

Group Size Estimates from Observer Counts

Good quality video was not available for all groups, so a method for estimating group size from observer counts was devised. Aerial counts of beluga whales were corrected for observer differences and the effect of encounter rate (group density in whales per second). Data from observers who had participated in the equivalent of one or more complete survey seasons (three surveys of the upper inlet and one survey of the lower inlet) were included in the analysis. Only counts made during passes considered by the observers to be excellent or good in quality (A or B) were used. Group sizes, estimated from video recordings, were used to represent the true group size.

This method provided a correction for availability and perception as well as the uncertainty in the time available to observers to count individual whales. The correction formula was derived by regression of the video-derived group sizes against the observer counts for those groups and an interaction term between the counts and the observed encounter rate with the intercept fixed at zero:

$$\hat{n}_{g,p,o} = \hat{b}_{1,o} c_{g,p,o} + \hat{b}_{2,o} \frac{c^2_{g,p,o}}{t_{g,p}}$$

$$Var(\hat{n}_{g,p,o}) = SE^2(\hat{b}_{1,o}) c^2_{g,p,o} + 2Cov(\hat{b}_{1,o}, \hat{b}_{2,o}) \frac{c^3_{g,p,o}}{t_{g,p}} + SE^2(\hat{b}_{2,o}) \frac{c^4_{g,p,o}}{t^2_{g,p}},$$

Where $\hat{n}_{g,p,o}$ is the size estimate for group g from a count by observer o during pass p, $\hat{b}_{1,o}$, $\hat{b}_{2,o}$ are the parameters estimated for each observer by linear regression, $c_{g,p,o}$ is the count by observer o of group g during pass p, $t_{g,p}$ is the time spent counting group g during pass p, $SE^2(\ )$ is the squared standard error of the regression coefficients, and $Cov(\ )$ is the estimated covariance of the regression coefficients.

This approach weights the correction formula to be most accurate for large groups where a bias would have the greatest impact on the abundance estimate. The first summand estimates

a multiplicative correction for counts to group size; the second summand estimates an additive bias proportional to the count multiplied by the density of the group. For aerial counts without recorded time, a single multiplicative correction was also estimated. The correction formula was applied to counts from groups where no group size estimate was available through the video analysis. These corrected counts were then averaged to estimate the group size:

$$\hat{n}_g = \frac{\sum_{J_g} \hat{n}_{g,p,o}}{J_g}$$

$$Var(\hat{n}_g) = \frac{\sum_{J_g} (\hat{n}_g - \hat{n}_{g,p,o})^2}{J_g - 1} + \frac{\sum_{J_g} Var(\hat{n}_{g,p,o})}{J_g^2}$$

where $\hat{n}_g$ is the estimated size of group g, and J_g is the set of corrected observer counts for group g.

Beluga, *Delphinapterus leucas*, Ethogram: A Tool for Cook Inlet Beluga Conservation?

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Introduction

An ethogram is a catalogue of mutually exclusive and objective behaviors or actions exhibited by an animal that avoids subjectivity and functional inference as to their possible purpose. It is a key tool that helps to quantify species-specific behaviors by describing the discrete, basic motor patterns that form the behavioral repertoire of a given species (Kikkawa and Thorne, 1971; Martin and Bateson, 2007). By describing and defining the behavioral inventory of a species as an ethogram, behaviors among different populations may be compared more thoroughly and accurately (Müller et al., 1998), as well as understood in terms of their causative and functional bases (Purton, 1978). The establishment of a basic ethogram is essential to the pursuit of further behavioral analyses of any given species (Scheer et al., 2004).

Despite the potential value of an ethogram to behavioral studies, only a few are available for a select number of species (Scheer et al., 2004). For marine mammals, the behavior of which has been studied extensively, the lack of ethograms cataloging their behaviors is surprising (a complete list of studies that include cetacean ethograms is given in Appendix A). The majority of cetacean ethograms focus on *Tursiops* (e.g., Mann and Smuts, 1999; von Streit et al., 2011), including perhaps the most comprehensive marine mammal ethogram, developed by Müller et al. (1998), who built upon previous observations to describe over one hundred behaviors of the bottlenose dolphins, *Tursiops truncates*, observed along the San Diego coastline.

Some of the behaviors described in the cetacean ethograms, such as leaping, are shared among different species (Norris and Dohl, 1979; Dudzinski, 1996; Müller et al., 1998), while other behaviors, such as spraying displayed by orca, *Orcinus orca* (Martinez and Klinghammer, 1978), are specific to only that species. Even though an ethogram based on the behaviors of one population is widely accepted as not representative for the species as a whole, that ethogram can serve as a reference and standard to understand basic species traits and to inform species management decisions.

Utilizing an ethogram to study a species of concern will provide a valuable tool to the emerging field of "conservation behavior," which uses the proximate and ultimate aspects of animal behavior to aid conservation decisions and reduce the loss of biodiversity (Buchholz, 2007). The conservation of cetacean species may benefit from ethogram use, as cetaceans are known to exhibit behavioral changes in response to a wide variety of anthropogenic disturbances including navy sonar, aircraft overflight, ship traffic, ice breaking, and marine construction (Richardson et al., 1995; Southall et al., 2007). In addition, the response of bowhead whales, *Balaena mysticetus*, and possibly other cetaceans to these anthropogenic disturbances varies with behavioral activity (Beale and Monaghan, 2004; Ellison et al., 2012). A complete catalog of behaviors for

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doi: dx.doi.org/10.7755/MFR.77.1.3

ABSTRACT— We present the first peer-reviewed wild beluga, Delphinapterus leucas, *whale ethogram, a comprehensive description and definition of behavioral states and events exhibited by the endangered stock of Cook Inlet beluga whales (CIBWs). The ethogram can be used to help quantify beluga behaviors and increase the utility of future and ongoing beluga behavioral studies, in Cook Inlet and for other populations. We tested the applicability of the ethogram by quantitatively examining spatial, temporal, and environmental effects on the probability of observing specific beluga behaviors in Eagle Bay and Eagle River (Knik Arm, Cook Inlet). Behaviors were observed and recorded from 2007 to 2011 between May and December when belugas are known to forage in the study area. We found that CIBWs are generally more likely to travel than mill in Eagle Bay, except when the tide is ebbing and above its midpoint, and that traveling occurred more frequently in Eagle River than in either the north or south sections of the bay. The results of our quantitative behavioral analysis can be compared with anecdotal observations of whale activity in the bay, and we encourage further investigation to more fully explain our results. The explicit language used to define this beluga ethogram will facilitate a more standard approach to behavioral studies of CIBWs, provide a means to quantify the response of CIBWs to anthropogenic activities, and allow comparison among multiple populations. Thus, this CIBW ethogram will potentially promote innovative approaches to help manage the endangered CIBW population.*

a cetacean may thus help researchers quantify changes in observed behavior due to different levels and types of disturbance for a cetacean population inhabiting an anthropogenically-altered environment and assist in directing management efforts.

One endangered stock that may benefit from a behavior-based management approach is the Cook Inlet stock of beluga whales (*Delphinapterus leucas*). This small population has been geographically isolated from other beluga populations for over 10,000 years and is also the most genetically distinct of the species (O'Corry–Crowe et al., 1997; Laidre et al., 2000). The size of the Cook Inlet beluga whale (CIBW) population decreased by half between 1994 and 1998, primarily due to unsustainable subsistence harvests, and has continued to decrease by 1.6% annually since 1999 (Hobbs et al., 2000; Hobbs et al., 2015).

The geographic range of CIBWs has also contracted substantially over the last several decades, with very few whales observed in lower Cook Inlet during the summer months and the area of highest concentration in the upper inlet near Anchorage, the largest city and port in Alaska (Rugh et al., 2010). The CIBW was federally listed as an endangered species in 2008, primarily because of the lack of population recovery after regulation of the Alaska Native subsistence hunt, a relatively small geographic distribution, and concerns about long-term population viability (Hill and DeMaster, 1998; NMFS[1]). Because very little research was conducted on CIBWs prior to their endangered listing, a dearth of literature exists on their basic ecology and behavior, and factors currently impeding recovery are unknown.

In this paper we present an ethogram of CIBW behaviors observed from May to December 2007 to 2011 in Eagle Bay and Eagle River in Knik Arm in the upper Cook Inlet, a frequent fall gathering area for the whales (Huntington, 2000; Hobbs et al., 2005; Rugh et al., 2010). It is our hope that this beluga whale ethogram will serve as a reference for future behavioral studies of CIBWs and other beluga populations. We also describe how CIBW behaviors vary by tide state and location within Eagle Bay, demonstrating how the application of our ethogram can increase both ecological and behavioral knowledge of CIBWs over varying temporal and spatial scales. Such knowledge will help direct future studies of CIBWs concerning their response to human disturbances within their critical habitat.

Methods

Study Area

Cook Inlet is a tidal estuary located in south-central Alaska and covers an area of approximately 20,000 km^2 with 1,350 km of coastline (Rugh et al., 2005). Extreme tidal fluctuations with a 9 m range result in strong currents up to 9–10 knots and tidal bores, which constantly alter the shoreline (Moore et al., 2000). Our CIBW behavioral studies were conducted in Eagle Bay and Eagle River, which are located in Knik Arm, upper Cook Inlet (Fig. 1).

Glacially-fed Eagle River flows through Eagle River Flats, a 866 ha estuarine marsh on Joint-Base Elmendorf-Richardson, before emptying into Eagle Bay. A complex interaction of physical forces influences the marine system of Cook Inlet, including those exerted by a high tidal range, glacial-fluvial effects from multiple river inputs, high degree of sedimentation, and the subarctic coastal climate of southcentral Alaska (Lawson et al.[2]). Direct anthropogenic influences on the study area are largely centered on the flats and include military training, both historic (Army artillery impact area since 1949) and current (winter firing of artillery into flats), as well as activities associated with the remediation of white phosphorus residues.

Ethogram

We developed our ethogram opportunistically from a U.S. Army monitoring project of CIBWs in Eagle Bay and Eagle River. Observations of CIBWs were carried out from 2007 to 2011 between the months of May and December when belugas gather in Eagle Bay (Huntington, 2000) and feed in Eagle River. Observations were conducted by two or three experienced observers using 12x45 power binoculars and high-powered spotting scopes from the north shore at the mouth of Eagle River, an advantageous survey location to view whales throughout Eagle Bay and in the mouth of the river.

During the 2007 field season, beluga observation protocol followed the ad libitum sampling technique (Altmann, 1974), with general field notes recorded when belugas entered Eagle Bay. From these observations, multiple beluga behaviors were initially defined and described. Beginning in 2008, a more systematic sampling approach was employed, which consisted of a group follow protocol and focal group sampling method (Altmann, 1974).

Observers tracked a group of whales over the course of a 20-min sampling period and defined the activity of the group based on the behavioral state of the majority of whales during the period. A "group" of whales was defined as the number of estimated animals sufficiently close in proximity to potentially be confused with each other (Mann and Smutts, 1999). A behavior that occurred over an extended period of time, such as milling, was considered a "state" (Martin and Bateson, 2007).

Within each sampling period, we estimated the number of whales using instantaneous scans over the 20-min period, though estimates were usually made within the first 10 min of the round after counting all of the individuals in a group(s), trying to minimize double counting. Whales were also classified as white, gray, or calf,

[1]NMFS (National Marine Fisheries Service) 2008. Conservation plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). NMFS, Office of Prot. Res., Juneau, AK, 122 p.

[2]Lawson, D. E., L. E. Hunter, S. R. Bigl, B. M. Nadeau, P. B. Weyrick and J. H. Bodette. 1996. Physical system dynamics, white phosphorus fate and transport, 1994, Eagle River Flats, Fort Richardson, Alaska. CRREL Rep. 4 p. prep. for U.S. Army Alaska, Fort Richardson.

and the location of whale groups at the start of each sampling round was approximated, based on a 8 x 6 cell grid superimposed on a map of Eagle Bay and Eagle River (Fig. 1). Each cell represented a 1 km^2 area. At the end of each day, an estimate of the total number of whales was made by adding up the total number of individuals counted across all independent whale observations per the study protocol.

During the 2011 field season, the beluga observation protocol was expanded for whales that entered Eagle River. Specifically, we included a fine-scale behavioral component, or "event," which we defined as a discrete behavior, such as flapping, that occurs at a certain point in time (Martin and Bateson, 2007). When an individual whale performed an event in the river, observers recorded the type of event, the time, and the state of the majority of the whales in the river at that time. Events were only recorded for whales in Eagle River up to the first turn in the river (Fig. 1) because of their proximity to observers, while states continued to be recorded for whales in both Eagle River and Eagle Bay.

Systematic observations were made on the Cook Inlet whales between 2008 and 2011. As our knowledge of the beluga behavioral repertoire has expanded, we constructed an ethogram of beluga behaviors frequently viewed in Eagle Bay and Eagle River and have added to it as new behaviors are described. Between 2008 and 2011 we also continued to refine and edit descriptions of the behaviors to be included in the ethogram. We present the ethogram in two categories, states and events, with video and photographs compiled for each behavior.

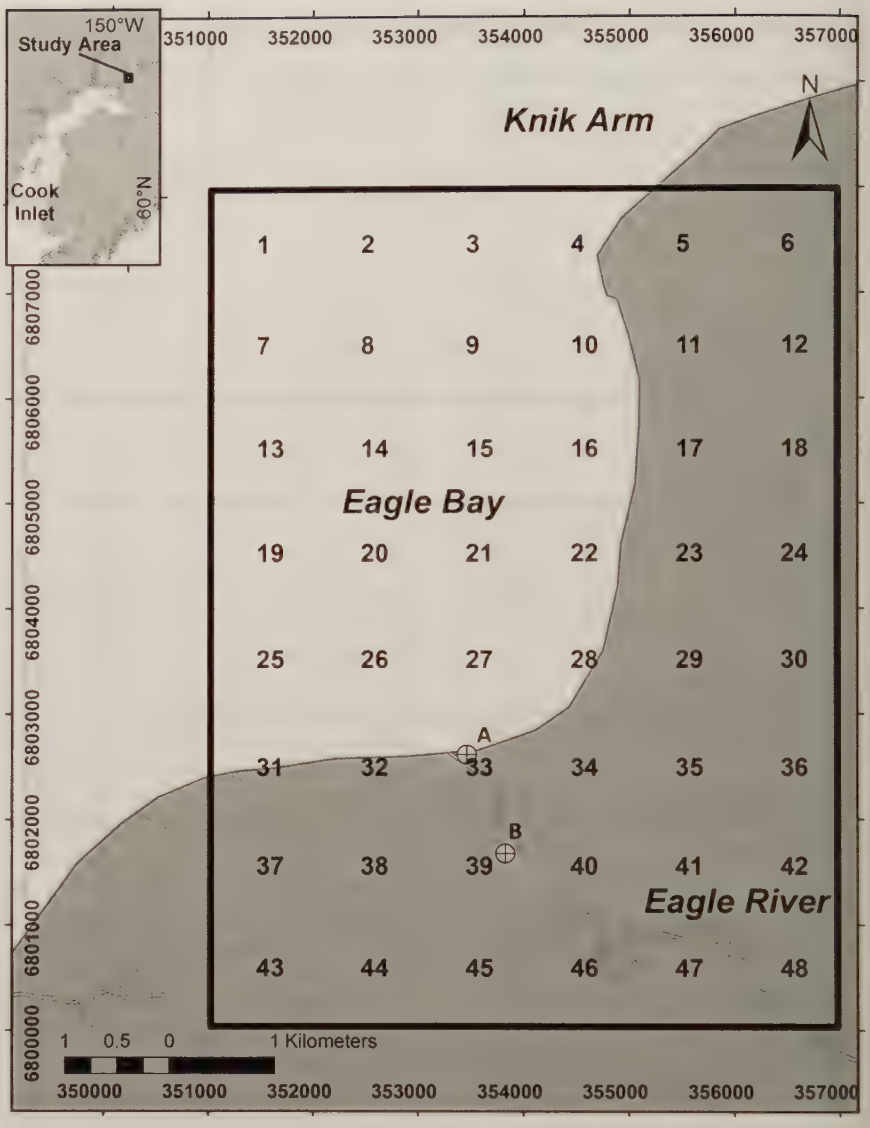

Figure 1.— Location of Eagle River and Eagle Bay in Knik Arm, Cook Inlet, Alaska, and superimposed grid for recording beluga whale visual locations. 1 cell=1 km^2 area. CIBWs only found in cells 1, 2, 3, 4, 7, 8, 9, 10, 13, 14, 15, 16, 19, 20, 21, 22, 25, 26, 27, 28, 31, 32, 33, and 39. Observations of whales in Eagle River conducted in mark "A" location and up river to mark "B". Map projection in WGS 84, UTM Zone 6 North (meters), declination 19° E.

Testing the Applicability of the Ethogram

This ethogram was developed to provide standard definitions so that beluga behaviors could be quantified and to standardize future studies involving Cook Inlet beluga life history and ecology, thus enhancing our overall understanding of their biology. We used the ethogram to describe the behavior of belugas in Eagle Bay and Eagle River and analyze the frequency of behaviors to corroborate the apparent relationship between tidal fluctuations and beluga movements and behaviors in the study site.

On a large temporal scale, beluga distribution within Cook Inlet is based primarily on proximity to rivers with Chinook salmon, *Oncorhynchus tshawytscha*, runs, rivers with medium flow accumulation, tidal flats, and areas with sandy coastlines (Moore et al., 2000; Goetz et al., 2007; Goetz et al., 2012). Daily beluga movement patterns, however, are largely determined by tides, and in upper Cook Inlet, it is believed that beluga travel is associated with tidal currents and direction (Ezer et al., 2008). Specifical-

ly, with a flooding tide belugas move up Knik Arm to utilize typically inaccessible mudflats and river mouth areas for foraging (Ezer et al., 2008).

In Eagle Bay, during the ice-free months the belugas seem to move and behave in a fairly predictable pattern relative to the tide cycle, though these conclusions have been based solely on anecdotal evidence collected from 2007 to 2011 in conjunction with the beluga monitoring project around Eagle River Flats.

After about a half of the ebb cycle, belugas travel south from areas north of the bay with the outgoing tide. Some bypass Eagle River, but usually at least one group enters the river and mills or travels up and down the river until about three-quarter ebb. Those that entirely bypass the river seem to move west and mill along the shore until they reach the sandbar at the southern end of the bay, where they remain to mill or leave the bay. When the tide begins to flood, the whales actively travel, following the flooding current across the mudflats to the north end of Eagle Bay. By three-quarters flood, the whales have disappeared around the north point of the bay on their way to upper arm areas that are probably only accessible at or near high tide.

Wheras these anecdotal patterns seem to be typical of the belugas in Eagle Bay in the ice-free months, their actual probability and frequency had not yet been documented. The ethogram provides a method to classify these behaviors by time period so that the probability of seeing a behavior can be related to the environmental variables, thus allowing quantification of beluga movement patterns.

For this analysis, we consider the two most frequently observed behavioral states, milling and traveling, as they were easily assessed across the entire study area compared to individual behavioral events, which generally require close proximity to the whale. Eagle Bay was separated into three areas (Fig. 1): "North Bay" (grid areas 4, 10, 16, 22, 28, 34), the "River" (areas 33, 39, 40), and "South Bay" (areas 31, 32, 25, 26), which is located adjacent to the previously referenced sandbar. For each 20-min period, tidal information from the Port of Anchorage tide station maintained by the National Oceanic and Atmospheric Administration was corrected with a half hour delay to account for the distance between the Port of Anchorage and Eagle Bay.

The tide cycle was divided into six categories: flood tide upper half and lower half, ebb tide upper half and lower half, at high tide or at low tide. Belugas were not observed in the bay during high tides, so we combined the remaining tide cycles into five categories: EbbAbove, EbbBelow, FloodAbove, FloodBelow, and Low.

Finally, behavior differences were thought to occur between August and the later months based on anecdotal observations made from Eagle River Flats so two time periods, "August" and "months other than August," were considered. Only data from 2011 were used, as observations from only 2011 provided sufficient information to determine tide states for each 20-min observation period. Each 20-min observation period from 2011 with whales present and either milling or traveling in these grid areas was included in the analysis. Periods without beluga sightings were omitted.

With the probability of the logged behavior as the dependent variable, and location, tide categories, and month as the independent variables, we used logistic regression (glm) in the statistical computing language and environment R version 2.13.1 (http://cran.r-project.org/) and the code editor Tinn-R version 1.16.1.4 (http://www.sciviews.org/Tinn-R/)) to estimate the probability of observing traveling as a behavior for a given 20-min interval in each area, under different tide categories and during August vs later months. We consider an additive model:

Probability(traveling behavior) ~
tidequarter, #+ Bay.Location +
Augustday,

with all categories initially represented individually and then combined into similar tide categories. We then used Akaike Information Criterion (AIC) in R in a stepwise elimination to identify the most parsimonious model.

Results

Ethogram

The ethogram described here follows the standard structure suggested by Martin and Bateson (2007) including events and states. Video sequences of all the definitions below can be found at https://www.youtube.com/watch?v=4x7N0NoHgnU. Images of feeding behavior provided by Stacy DeRuiter.

States

1) Milling: Whales surfacing in a more or less constantly varying direction, especially in relation to each other. They may remain in the same area or drift/move with the tide or current. 2) Traveling: Whale or whales moving in a consistent, unidirectional fashion relative to other individuals in a group. Traveling whales typically appear to move in a purposeful, coordinated manner, most often with the direction of the tidal current. An exception to this rule is that when traveling in rivers, whales may travel against the water flow. A single traveling whale moves forward with few to no lateral deviations in course.

Events

1) Bubbling: A whale blows underwater or near the surface and creates a cloud of bubbles that splash at the surface. This definition does not include the normal exhalation that sometimes occurs immediately prior to surfacing.

2) Fast Dive: Similar to the diving behavior state but more rapid and always accompanied by significant surface disturbance from the beating tail fluke. The acute downward angle bending may be absent or less dramatic.

3) Feeding: Whale usually observed in the "prey pursuit" (no. 7 below) behavioral event just prior to feeding. The distinction between the two events

is that a prey item is observed in the whale's mouth during feeding but not during prey pursuit. Visual observation of prey in a whale's mouth is extremely rare, owing to the turbid waters of Knik Arm combined with the tendency for belugas to ingest prey whole. To capture instances when prey was not observed in a whale's mouth, yet feeding had likely occurred, we added the following language to the definition of a feeding event: a prey-pursuit event which includes a whale driving a prey item onto land or into the air, followed by observation of a whale or pursuit wake at the point of prey reentry into the water, and the observer has more than 50% confidence that the prey item was captured (e.g., as indicated by a violent surface disturbance at the point of reentry followed by an immediate cessation of observable activity); note that all three conditions must be met for this secondary definition to apply.

4) Flapping: Pectoral or caudal fin slams the surface and creates splash. Multiple flapping in sequence is considered a single event, unless another event is observed between flapping.

5) Floating: Whale observed at the surface with some portion of its body visible for an extended period of time (typically 10 sec or more) and with little to no directed movements. The whale moves passively with the current and does not transition into prey pursuit as often seen in side-scanning (no. 8 below).

6) Normal Dive: Surfacing whale bends its dorsal surface at an acute downward angle, slipping beneath the surface of the water with the tail flukes usually emerging completely out of the water and being the last part of the whale seen prior to complete submergence; this action is slow, almost casual.

7) Prey Pursuit: Whale exhibits sudden or explosive movements, often forward but may include rapid changes in direction and depth, always resulting in a fast-appearing linear wake, violent disturbance of water, or a combination of the two. No interactions between whales are observed prior to or during this event to avoid confusion with social interactions.

8) Side-scanning: Whale swims (often very slowly) at the surface with the lateral aspect of its body visible. The pectoral flipper, lateral surface of the body, tail fluke, or a combination of these parts, is visible, often for 30 sec to several minutes. This behavioral event is often followed by explosive movements of the tail as the animal moves rapidly forward in pursuit of prey.

9) Snorkeling: A surfacing whale lifts its head gently to the surface in such a manner that only the melon, blowhole, and a small portion of the dorsal surface just posterior to the blowhole are visible. After gas exchange has occurred, the whale then gently lowers its head below the surface. The dorsal ridge is never seen during a snorkeling event. Note that this behavior often makes detection of whales difficult from a distance as it reveals only a small portion of the whale and leaves a rapidly dissipated, relatively small (several feet diameter), concavity at the surface of the water.

10) Social Interaction: Typically two, but sometimes more, whales engage in physical contact, chasing each other, or tail flapping each other, always followed by one of the individuals moving away from the other. This event does not apply to mother-calf interactions.

11) Spy Hopping: Whale emerges from the water with its head held vertically above the water, to at least eye level, but without the pectoral flippers being above the water's surface, and remains in this position for at least several seconds before submerging vertically with its head submerging last. The eyes are usually observed in a spy-hopping beluga.

12) Tail up: Caudal fin and sometimes part of the peduncle is observed above the surface, as if the whale is diving, but these remain in the air for an extended period of time (5 sec or more).

13) Other: Behavior exhibited by whale does not fall into one of the established event categories.

14) Unknown: Behavior not fully observed; observer cannot confidently place behavior into one of the established event categories.

Testing the Applicability of the Ethogram

A total of 659 h 40 min of observations from 3 June until 14 Dec. 2011 were collected. From these, 64 h 20 min were made in the presence of belugas and were included in the analysis.

In the initial analysis we found that EbbBelow (estimate = 1.53 (SE = 0.56), $z = 2.76$, $p < 0.01$), FloodAbove (estimate = 2.36 (SE = 0.83), $z = 2.83$, $p < 0.01$), FloodBelow (estimate = 1.90 (SE = 0.60), $z = 3.18$, $p < 0.01$), and Low tide (estimate = 1.92 (SE = 0.78), $z = 2.45$, $p < 0.01$) categories were statistically different from EbbAbove, but not from each other, and so they were grouped together for further analysis so that the tide quarter variable was either EbbAbove or not. The stepwise process removed the Augustday variable, as date was not found to have any effect on the probabilities, leaving the probability to be determined by the location and whether or not the tide was in the EbbAbove category.

The final logistic regression model was used to calculate the probabilities of observing travelling behavior when the tide was ebbing and was above half for that cycle (EbbAbove) for each bay location. Across all locations, traveling is more frequently observed during the grouped tide quarters than during the EbbAbove tide quarter (Fig. 2A). During the grouped tide quarter, traveling is significantly more likely to occur in Eagle River than either north or south Eagle Bay, while milling is significantly more likely to occur in the north section of the bay than in the river. During the EbbAbove tide quarter, belugas are in general more likely to be milling (Fig. 2B), but when traveling, the belugas are more likely to be found in the river than any other area of the bay.

Discussion

In total we cataloged two behavioral states and thirteen behavioral events

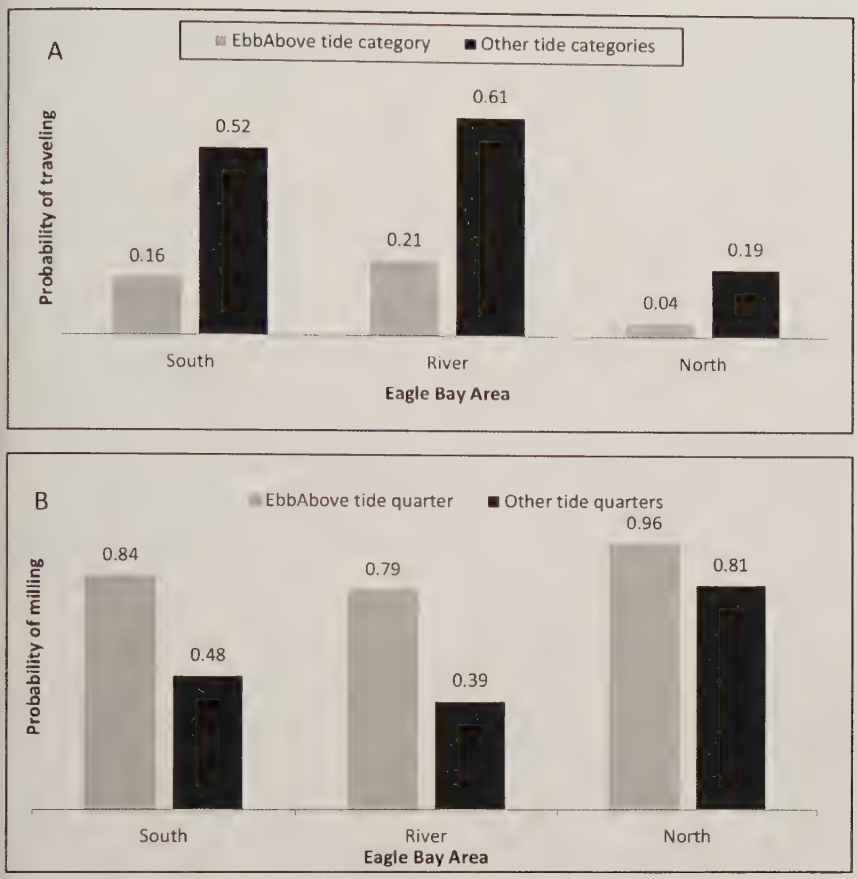

Figure 2.—The probabilities of observing belugas in the behavioral state of traveling (A) and milling (B) at above half tide level during an ebb tide versus all other tide stages combined, in three different areas of Eagle Bay and Eagle River, Knik Arm, Alaska, 2011.

displayed by the Cook Inlet beluga whales in Eagle Bay and Eagle River to establish the first peer-reviewed ethogram for wild beluga whales. In contrast with the extensively described behaviors for *Tursiops* (Müller et al., 1998) and *Stenella longirostris* (Norris and Dohl, 1979), the range of behaviors shown by CIBWs is quite small, which is explained, in part, by the lack of aerials in the beluga behavioral repertoire and by the turbid water present in Cook Inlet, which prevents identification of behavior occurring below the immediate surface layer.

We also demonstrated one application of the ethogram, the quantification of behavioral patterns exhibited by CIBWs, in relation to location within Eagle Bay and tide stage and level. CIBW behavioral patterns were found to significantly vary with these variables within the study area. Other cetaceans, such as the bowhead whale, also exhibit behaviors that correlate with naturally varying factors including season and water depth (Würsig et al., 1984; Richardson et al., 1995). We found a relatively high probability of observing whales traveling during the majority of the tide cycle, which in general supports previous anecdotal observations. This result makes logical sense, as average current velocity in Cook Inlet is around 3 kn but can extend up to 12 kn (Moore et al., 2000); thus the whales will expend less energy traveling with the current than milling potentially against the current.

However, some of the results of the tidal analysis contradicted the expected movement and behavioral patterns of the whales in Eagle Bay. For example, the data analysis shows that CIBWs more frequently mill than travel in the bay only when the tide is ebbing and above its midpoint. As the whales will move as far up the arm as possible during the high tide (Ezer et al., 2008), it may be that the majority of CIBWs traveled up Knik Arm and out of sight with the incoming tide and had not yet returned to the bay during that tide quarter. There was a small group of whales during the study period that was noted to swim against the tide at times and to enter Eagle Bay when the majority of whales were not present. It is possible that the behavior of these outliers influenced this result.

The other major finding of the analysis was that CIBWs more frequently travel in Eagle River during all tide stages than in any other area of Eagle Bay. In general, we observed more milling in the north and south areas of the bay as compared to the river. In contrast, anecdotal observations have suggested that the whales travel down from the north in Eagle Bay during the ebbing tide with some whales stopping to mill in Eagle River. The higher probability of observing milling in the north and south regions may be due to the fact that milling inherently occurs over a greater temporal scale whereas traveling through an area occurs more quickly; thus as the analysis was a function of duration of beluga observation, the chances of observing milling in a given area were greater than those of traveling.

It is less clear why CIBWs appear to travel more in the river than any other area. One possible explanation is that the current of Eagle River forces the whales to continually travel with or against the direction of the river current. The current at the mouth of the river is slower and may be more conducive to milling, and thus the whales would likely expend less energy milling just outside Eagle River than within the river itself. Another possible explanation that may operate in conjunction with the previous reasoning

is that the primary foraging grounds in Eagle River for CIBWs may be upriver and out of sight of observers on Eagle River Flats. Hence, the whales would frequently be observed traveling in the river in order to access their foraging sites. Further investigation using the ethogram of the specific events exhibited by CIBWs in Eagle River will provide a more complete explanation of these behavioral patterns.

We also acknowledge that certain sources of error may have affected our tidal analysis. Some of the unexpected behavioral results, such as frequent milling in the north bay, may stem from unknown, uncontrollable variables in Knik Arm, such as variations in local bathymetry or the size and timing of upper Cook Inlet salmon runs. Observer bias may have also played a role, as six different observers documented CIBW states, and there may have been discrepancies between their categorizations of states and events.

Furthermore, it is widely admitted that individual differences in the behavior of wildlife should be considered when analyzing a population. Individual differences in age, sex, size, aggressiveness, learning ability, past experience, heterozygosity, and a myriad of other variables can all affect how an animal reacts to a given situation and may determine the success or failure of a management strategy or a conservation initiative (Festa-Bianchet and Apollonio, 2003).

In addition, the use of both the focal group sampling method and the fine-scale behavioral sampling has several limitations in the development of our ethogram. First, behavioral sampling in the study area is limited to activities above the water line due to the extreme turbidity of Knik Arm. In the future, greater integration of DIDSON sonar imaging (Sound Metrics Corp.[3]) into the monitoring project may provide a better understanding of subsurface CIBW behaviors. It is also possible that the whales may exhibit behaviors further out in Eagle Bay that would not be entirely visible to observers stationed at the mouth of Eagle River.

Furthermore, CIBWs may exhibit different behaviors in other areas of Cook Inlet, as unusual events have been recorded for whales observed in the Little Susitna River (Easly-Appleyard et al.[4]). Because of these limitations, our ethogram may underrepresent the total number of behaviors displayed by CIBWs and thus the catalog may be expanded to include new behaviors observed in the future; however, we believe that the present ethogram provides a general illustration of behaviors one might observe in this population.

Conservation Implications

The goal of this study was to develop an ethogram for CIBWs and demonstrate its quantitative use to enhance understanding of CIBW behavioral patterns. Facilitating cooperation among scientists studying CIBW behaviors is of particular importance due to the whales' endangered status. Moreover, the integration of visually observed behaviors with acoustic behavior can further expand knowledge of CIBW life history and ecology. Several recent and ongoing CIBW monitoring projects in Cook Inlet, including a remote photo-based monitoring study (Easly-Appleyard et al.[4]) and a photo-identification project (McGuire et al.[5]) incorporate a behavioral component. We hope that our ethogram will enable greater collaboration among these various groups and encourage more behavioral studies by standardizing the behavioral language of CIBWs.

In addition, we show with our ethogram a correlation between CIBW behavioral state and environmental variables. Future studies should focus on whether CIBW behavioral states are influenced by anthropogenic disturbances such as seismic operations in Cook Inlet. Studies on bowhead whales demonstrate that traveling whales spend less time near the surface when in the vicinity of seismic operations, while feeding and socializing whales were more tolerant of such activities (Robertson et al., 2013). Recent seismic activities in Cook Inlet have included requirements to suspend operations when protected marine mammals, like CIBWs, are observed entering a defined activity zone.[6] However, if CIBWs' sensitivity to this disturbance increases under a certain behavioral state, like travelling for instance, observers may miss CIBWs during their surveys (e.g., Miller et al. 2005; Harwood et al. 2010), as might happen if the whales spent more time underwater. Thus, with continued development in Cook Inlet, understanding and quantifying how human activities alter CIBW response in the context of a given behavioral state will result in more accurate density and population estimates near these operations (Robertson et al., 2013).

In Eagle River and Eagle Bay specifically, military activities may influence CIBW behavior, yet without objective and definitive descriptions of behavioral states and events, there has been no way to quantify the level of behavioral changes caused by these activities. Our study demonstrates the frequency of CIBW behavioral patterns relative to naturally occurring factors, which provides a CIBW behavior baseline in the absence of direct human disturbances. Further standardized behavioral observations of CIBW in Eagle Bay and Eagle River concurrently with military operations will al-

[3]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[4]Easly-Appleyard, B., L. Pinney, L. Polasek, J. PEasley-Appleyard, B., L. Pinney, L. Polasek, J. Prewitt, and T. McGuire. 2011. Alaska SeaLife Center Cook Inlet beluga whale remote monitoring Pilot Study. Final Rep. from Alaska SeaLife Center, Seward, 49 p. (http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/cib_susitna093011.pdf).

[5]McGuire, T., and C. Kaplan. 2009. Photo-identification of beluga whales in upper Cook Inlet, Alaska. Final rep. of field activities in 2008. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for Nati. Fish and Wildl. Found., Chevron, and ConocoPhillips Alaska, Inc.

[6]Editorial, 2012. Responsible seismic operations in Cook Inlet, Alaska. Accessed 22 Aug. 2013. http://www.apachecorp.com/News/Articles/View_Article.aspx?Article.ItemID=2480

low for a comparison of the observed CIBW behavior with and without human disturbances, and thus enabling researchers to quantify the responses of CIBWs to these operations.

Finally, with the likely development of a hydroelectric dam in the Little Susitna River in the next few years, and its potential impacts on CIBW anadromous prey (Alaska Energy Authority[7]), the ability to unambiguously define CIBW foraging behaviors around construction events, may provide insight into changes in the behavior of belugas in response to changes in prey distribution and availability, or changes in the Susitna Delta itself resulting from changes in hydrology or siltation.

Acknowledgments

This study would not have been possible without the tireless efforts of Richard Graham and numerous beluga observers, including Kori Blakely, Evana Burt-Toland, Lance Downing, Sarah Jones, Marcus Mustin, Amber Stevens, Carly Wickhem, and Cory Walch. Special thanks also to Brent Koenen of Joint-Base Elmendorf Richardson for helping make this project a reality. Photographic images included in the ethogram video were provided by Stacy DeRuiter by way of Tamara McGuire of LGL Associates. Kim Shelden of the National Marine Mammal Laboratory prepared Figure 1. The findings and conclusions in the paper are those of the authors and do not necessarily represent the views of the National Marine Fisheries Service.

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Appendix: Cetacean Ethograms by Species

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Traditional Knowledge and Historical and Opportunistic Sightings of Beluga Whales, *Delphinapterus leucas*, in Yakutat Bay, Alaska, 1938–2013

W. G. LUCEY, E. HENNIGER, E. ABRAHAM, G. O'CORRY-CROWE, K. M. STAFFORD, and M. CASTELLOTE

ABSTRACT—A total of 76 confirmed sighting events of beluga whales, Delphinapterus leucas, *were gathered from 1938 to 2013 in Yakutat Bay, Alaska. The sightings were a mix of incidental observations from airplane pilots and commercial fishermen as well as directed ground and aerial surveys. The earliest sightings are anecdotal, with the first known observation recalled from the summer of 1938. Throughout the observation period the average group sighting was 6 whales with a low of 1 animal and an estimated high of 26 animals. Overall, there is little traditional or historical knowledge about the Yakutat Bay belugas, including whether they were a hunted species. However, the study revealed the existence of the local name for belugas "Kuyeedaayee" (skin under the stars), which was either of Tlingit origin or, possibly, from the now extinct Eyak language. The fact that there is a Tlingit/Eyak name for the animals supports the theory, and the genetic evidence, that they have inhabited Yakutat Bay for longer than the sighting record indicates. This report includes four summaries of observations from local residents who are most knowledgeable about Yakutat Bay.*

Introduction

Local people have long known about the existence of beluga whales, *Delphinapterus leucas*, in Yakutat Bay, Alaska, although this knowledge was restricted to those connected with seal (Phocidae) hunting and commercial fishing on the Manby shore on the west side of Yakutat Bay. Current knowledge is based on intermittent opportunistic sightings and some directed research (e.g., Hubbard et al., 1999; Laidre et al, 2000; O'Corry-Crowe et al.[1,2]). To gather information about historical and current sightings of belugas in the Yakutat region, a directed interview effort of the local people who were most knowledgeable about Yakutat Bay was undertaken and opportunistic sightings, the majority of which were from the past decade, were collected.

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doi: dx.doi.org/10.7755/MFR.77.1.4

Methods

Both informal and formal efforts were made to gather information about local and traditional knowledge of beluga whales in the Yakutat area. A formal gathering was held in May 2005 by The City and Borough of Yakutat, using grant funding from the U.S. National Park Service, to interview Yakutat Tlingit Tribal Elders regarding their knowledge of belugas. The elders group was selected and invited by the Yakutat Tlingit Tribal administration and were provided stipends through grant funding. U.S. National Park Service funding was matched by funds from the Alaska Sea Otter and Steller Sea Lion Commission. The meeting was overseen by Henry Huntington who is well versed in formal traditional ecological knowledge (TEK) methods (Huntington, 2000). Prepared questions were distributed by the tribal wildlife biologist. Informal information, or casual conversation was collected from airplane pilots, commercial fishermen, and other agency personnel who shared observations of beluga whales with the city biologist (Lucey). These observations made up half of the sightings and are included to augment formal conversations with elders and direct observations from various marine mammal scientists conducting various wildlife surveys in the area. Dates and locations of sightings from the Yakutat area and as reported in peer-reviewed literature were also included.

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Results and Summaries of Local Residents' Observations

A total of 76 beluga observations were recorded between 1938 and 2013, including calves sighted at regular intervals (Table 1). Fifty-three sightings came from various natural resource agency staff, 12 sightings came from commercial fishermen, 4 from solo pilots, and 7 came from subsistence hunters and elders. Beluga group size averaged 6 (1–26). Although the largest group sizes were reported in 1938 and 1976, over the past 40 years the

Table 1.—All sightings of beluga whales in Yakutat Bay from 1938 to 2013 with date, observer, location, and notes.

Date	Observer	Affiliation[1]	Location	# of whales	Notes
Summer 1938	George Valle Sr.	SH	Manby Shore	15–20	First seen during seal hunting
Summer 1968	Bob Fraker	CF	Manby Shore	8–10	Common while fishing
31 May 1976	Calkins (cited in Laidre et al., 2000)	NMFS	Yakutat Bay	21+5	Aerial survey
20 April 1979	Cox and Ranney	Pilots	Esker Creek	6	4 adults, 2 calves
15 July 1979	Mallot	CF	Between Blizhni and Manby	Several	Set net fishing
15 July 1980?	Pavlik, Matsko	CF	In Esker Creek		Set net fishing
24 Sept 1993	Ream	NMFS	Disenchantment Bay	2	
19 Feb 1997	Hubbard et al., 1999	MMS	Disenchantment Bay	10	1 gray/white whale
1 July 1997	Adams, Sr.	YTT	Disenchantment Bay	Small pod	Charter trip
20–25 Aug 1997	Small, Lowry	ADF&G	Bancas Point	1–5	Aerial survey
Early Sept 1998	Donahue	CF	Mouth of Icy Bay	6	Power trolling
16 Nov–8 Dec 1998	Molthen, Howard (cited in Hubbard et al., 1999)	USCG	Disenchantment Bay	6–11	
14–15 Aug 2000	Herter, Plafker	USGS	Bancas Point	4–8	Glacier study
7–26 May 2002	Jansen, Adams, Jr., Lucey	USFS,NMFS,YTT	Beluga Bay	5	Biopsy attempt
19–20 Sept 2002	O'Connor, Lucey, Adams, Jr., R. Sensemeier	USFS & YTT	Beluga Bay	6–7	Biopsy attempt
24 March 2003	Johnson	ADF&G	South Khantaak	1	Orca survey
24 April 2003	Russell, Lott	YCA	Disenchantment Bay	9–10	Glacier survey
26 April 2003	Lucey	USFS	Disenchantment Bay	9	Glacier survey
3 May 2003	Lucey, Adams, Jr.	USFS,YTT	Beluga Bay	9	Missed biopsy attempt
6 May 2003	Lucey, R. Sensemeier	YTT, USFS	Beluga Bay	9	Biopsy attempt
21 May 2003	Russell	YCA	Beluga Bay	8	Glacier survey
1 Sept 2003	Adams, Jr, Lucey	CBY, YTT	Beluga Bay	6	One biopsy taken
19 May 2004	Hartley	Alsek Air	Disenchantment Bay	10	Scenic flight
23 May 2004	Dahle	NMFS	Beluga Bay	2–3	Seal survey NMML
31 May 2004	Dahle	NMFS	Beluga Bay	8	Seal survey NMML
1 June 2004	Dahle	NMFS	Beluga Bay	6	Seal survey NMML
3 June 2004	Dahle	NMFS	Haenke Stream	6	Seal survey NMML
15 June 2004	Dahle. Lucey	NMFS/CBY	Haenke Stream	2	Seal survey NMML
18 July 2004	Dahle. Lucey	NMFS/CBY	Turner Glacier	6–7	Seal survey NMML
19 July 2004	Dahle	NMFS	Turner Glacier	5–6	Seal survey NMML
3 Aug 2004	O'Connor, Rush	USFS	Turner Glacier Bancas Side	9	Kayak trip
4 Aug 2003	O'Connor, Rush	USFS	Turner Glacier	12	Kayak trip
19 Aug 2004	Russell	YCA	Disenchantment Bay	8	Scenic flight
26 April 2005	Hartley	Alsek Air	Beluga Bay	10–12	Beluga survey
3 May 2005	O'Corry-Crowe, Bonin	NMFS	Beluga Bay	10–12	Beluga survey
7 May 2005	Jansen	NMFS	Turner Glacier Haenke Side	4	Seal survey NMML
16 May 2005	Jansen	NMFS	Beluga Bay	3-4	Seal survey NMML
17 May 2005	Bonin, Dahle	NMFS	Beluga Bay	4	Seal survey NMML
17 May 2005	Jansen	NMFS	Beluga Bay	2	Seal survey NMML
22 May 2005	Jansen	NMFS	Beluga Bay	8	Seal survey NMML
23 May 2005	Henniger	YTT, NMFS	Turner Glacier Haenke Side	5–6	Seal survey NMML
24 May 2005	Jansen, Dahle	NMFS	South of Haenke River mouth	6	Seal survey NMML
26 May 2005	Dahle, Libby	NMFS	Turner Glacier	3–4	Seal survey NMML
30 May 2005	Jansen, Dahle	NMFS	Beluga Bay	3	Seal survey NMML
31 May 2005	Jansen, Dahle	NMFS	Turner Glacier	5–6	Seal survey NMML
1 June 2005	V. Sensemeier	YTT	Beluga Bay	4	Seal survey NMML
5 May 2006	Lucey	CBY	Disenchantment Bay	5	Skiff survey
14–16 July 2006	Rush	NPS	Esker Stream	13	NPS cabin repair
14 July 2006	Hartley	Alsek Air	Esker Stream	6	Scenic flight
27 June 2007	Lucey	CBY	Turner Glacier	1	Beluga survey
1 July 2007	Bullard	SH	Nunataak Fiord	1	Subsistence hunting trip
3 Aug 2007	Lucey	CBY	Beluga Bay	8	Beluga survey
9 Oct 2007	Lucey	CBY	Center of Hubbard	4	Beluga survey
15 Jan 2008	H. Gray	CF	Point Latouche	1	Winter trolling
14 Feb 2008	Lucey	CBY	Turner Glacier	4–6	Beluga survey
15 Mar 2008	I. Totland	CF	Yakutat Bay-Pinnacles	1	Winter trolling
5 April 2008	O. Totland	CF	Yakutat Bay Logan's Bluff	1	Winter trolling
10–17 May 2008	O'Corry-Crowe	HBOI, UW	Beluga Bay-Turner Glacier	10	Field camp
23 June 2008	Jacobsen	CF	Yakutat Bay-North Khantaak	1	Long lining
8 Oct 2008	Lucey	CBY	Beluga Bay	4	Seismic mitigation survey
19 Feb 2009	Firestack	CF	Pt. Latouche	1	Winter trolling
24 Aug 2009	Larson	UAF	Esker Creek	3–4	Glacier research
8 Sept 2009	Lott	NPS	Turner Glacier	4–5	Park Service flight
10 May 2010	Hartley	Alsek Air	Turner Glacier	5–6	Tourist flight
2 May 2010	Lucey	CBY	Turner Glacier	4	Beluga survey
20 Aug 2010	Jansen	NMFS	Bhlizini Point	6	Harbor seal survey
21 Aug 2010	Lucey, O'Corry-Crowe	CBY, HBOI	Bancas point	7–9, 1 calf	Beluga survey
12 Sept 2010	Williams	CF	Pt Latouche	1	Whale eating brown fish
21 Sept 2010	Scott	ADF&G	Esker Creek	7–9	Bear telemetry flight 6:38 pm
25 May 2011	Lucey, Koller	CBY	Beluga Bay	2	Far side near Turner
2 July 2011	Lucey, Heerman	CBY	Turner Glacier/Bancas side	3	Milling near edge of Turner
29 July 2011	Lott	NPS	Bancas Point	5–6, 1 calf	Swimming rapidly
6 Aug 2011	Jansen, Lucey	NMFS, CBY	Esker Creek	9–10	edge of sediment plume
25 July 2012	Lucey	CBY	Esker Creek	8	Feeding in sediment plume
26 July 2012	Thompson	NPS	Esker Creek	7	Swimming
10 Aug 2012	Lucey	CBY	Turner Glacier /Bancas Side	4	Swimming
13 July 2013	Lucey	CBY	Esker Creek	6	Swimming

[1]Key: AA = Alsek Air; ADFG = Alaska Department of Fish and Game; CBY = City and Borough of Yakutat; CF = Commercial Fisherman; HBOI = Harbor Branch Oceanographic Institute; NMFS = National Marine Fisheries Service; NPS = National Park Service; SH = Seal Hunter; UAF = University of Alaska Fairbanks; USCG = U.S. Coast Guard; USFS = U.S. Forest Service; USGS = U.S. Geological Survey; YCA = Yakutat Coastal Airlines; YTT = Yakutat Tlingit Tribe.

number of belugas seen in Yakutat Bay has remained fairly stable at roughly 6–10 individuals. Most sightings occurred from April to September in the Disenchantment Bay region (Fig. 1).

Summarized here are conversations with various members of the community of Yakutat, Alaska, in 2005 through 2013. Many conversations were informal and occurred at barbecues and local stores. Additional information was collected during an elder's meeting, that took place in May 2005 in Yakutat, conducted with the specific intent of learning about Yakutat belugas and Steller sea lions, *Eumatopias jubatas*. This meeting revealed the local name and oldest known observation of the Yakutat belugas.

The Pavlik Family

The following informal information comes from several conservations with members of the Pavlik family, beginning in 2001. Mike Pavlik was paid for this information with rough-cut lumber from a local sawmill and a fuel stipend.

The Pavlik family has been in Yakutat since the 1940's. The father, Mike Pavlik, Sr., of Czechoslovakian descent, married Mary Pavlik, a Tlingit woman from Klukwaan, Haines, Alaska, and they had several children.

Mike Pavlik specialized in fishing on the Manby Shore (Fig. 1) during the 1950's and 1960's, now part of Wrangell-St. Elias National Park and Preserve. Over the decades, the family has spent hundreds of days observing the fish runs and wildlife in the area. They were familiar with the Yakutat beluga population long before the scientific community recorded official sightings. They also hunted the Disenchantment Bay harbor seals, *Phoca vitulina*, and continue to do so today.

Mike said that during his fishing days, the belugas would pass by occasionally while they were gillnetting Pacific salmon, *Oncorhynchus* spp., in and outside of the mouth of Esker Creek. He said that there were usually around 15–20 belugas in a group, though he was not sure of the exact number or time of year. The main commercial fishing season is June–September. He said they never bothered the beluga whales, as they were a special event that broke up the constant work of tending nets and salting fish. His son Andy would drift out amongst the whales and take pictures of them as they played and fed around the river mouth.

Mike's son Johnny Pavlik and a family friend, John Matsko, were good sources of informal information. They tell of accidentally catching a beluga in a net at the mouth of Big Esker Creek. John Matsko is a present-day fishing guide and past partner of the Pavlik's commercial fishing enterprise. The incident occurred around 1980 while Johnny was fishing by himself. He saw a great surge coming down river and went for his net as he wasn't sure what was making the waves. It turned out to be a pod of belugas. One of the whales tried to go under the net as he was lifting it out of the way and its tail became entangled in the lead line. Johnny struggled with the whale for a short time before his brother, Rudy Pavlik, and John Matsko arrived in another skiff.

All three of the fisherman held the whale's blowhole at the surface while they cut it free. This took over an hour. John Matsko stated that the whale was relaxed, swimming along with them as they drifted in the bay. He was amazed by this as the whale was mostly free for a long portion of this time and it could have easily swam away. They took extra time and were successful in cutting off most of the material; the whale recovered and calmly swam off. Other than this one incident, there were no known gillnet and beluga interactions in the Yakutat area.

Mike Pavlik's youngest son, Rudy Pavlik, is the top harbor seal harvester in town, according to the Alaska seal harvest survey published annually by the Alaska Native Harbor Seal Commission (Wolf et al., 2013). He is the chief provider to the community, donating and selling large amounts of seal meat, oil, and skins. Another area where Rudy has seen the belugas is in the Dangerous River southeast of Yakutat. However, Rudy did not give details on this sighting though it probably ranged from the early to mid-1980's.

Jeremiah Pavlik, Mike's grandson, has reported seeing pods of belugas on the Khantaak Pinnacles twice on flights over to Manby during the late 1990's and early 2000's. He feels that the whales are staying closer to the ice more than in years past when they were frequently seen while fishing in areas around Grand Wash. Jeremiah attributes this to the rapid rise in cruise ship traffic to the area.

George Valle, Jr.

George Valle died in 2011. He told his story during the formal elder's meeting, with charming wit and humor. He began hunting and fishing on the west side of Yakutat Bay in 1938, when he was 10 years old, and continued to do so through the late 1990's. Recorded transcription: "I fished over [Manby] in the summer for 7 years... Spoon River, Sudden Stream, Kahliahk. I fished all the rivers. And I'm still poor [Laughing]." Surprised at the subject of this interview and hearing of research on the belugas in Yakutat, George said, "I thought people knew about it all the time. I was surprised when everybody got all excited about them all of a sudden. They had to been there all the time."

George: "That beluga, the first one I seen... the first time I saw one was in...1938 at 10 years old. I was seal hunting with my grandfather. I never asked him about it. I just see them. I was ten years old...He had me working all the time, rowing the boat to the ice, from 3:00 in the morning to just before dark. Hard candy and heart attack... [He laughs]. We saw 'em up around... the Hubbard Glacier. The first one I saw...I never asked questions or anything. I never did ask my grandfather...what they were or anything. We didn't look for them...we were looking for seals. But I just happened to see them up here. We'd hunt back in [front of Turner Glacier, Haenke Glacier, and Beluga Bay area]." Beluga Bay was filled with a landslide in 2012. Few surveys have been conduct-

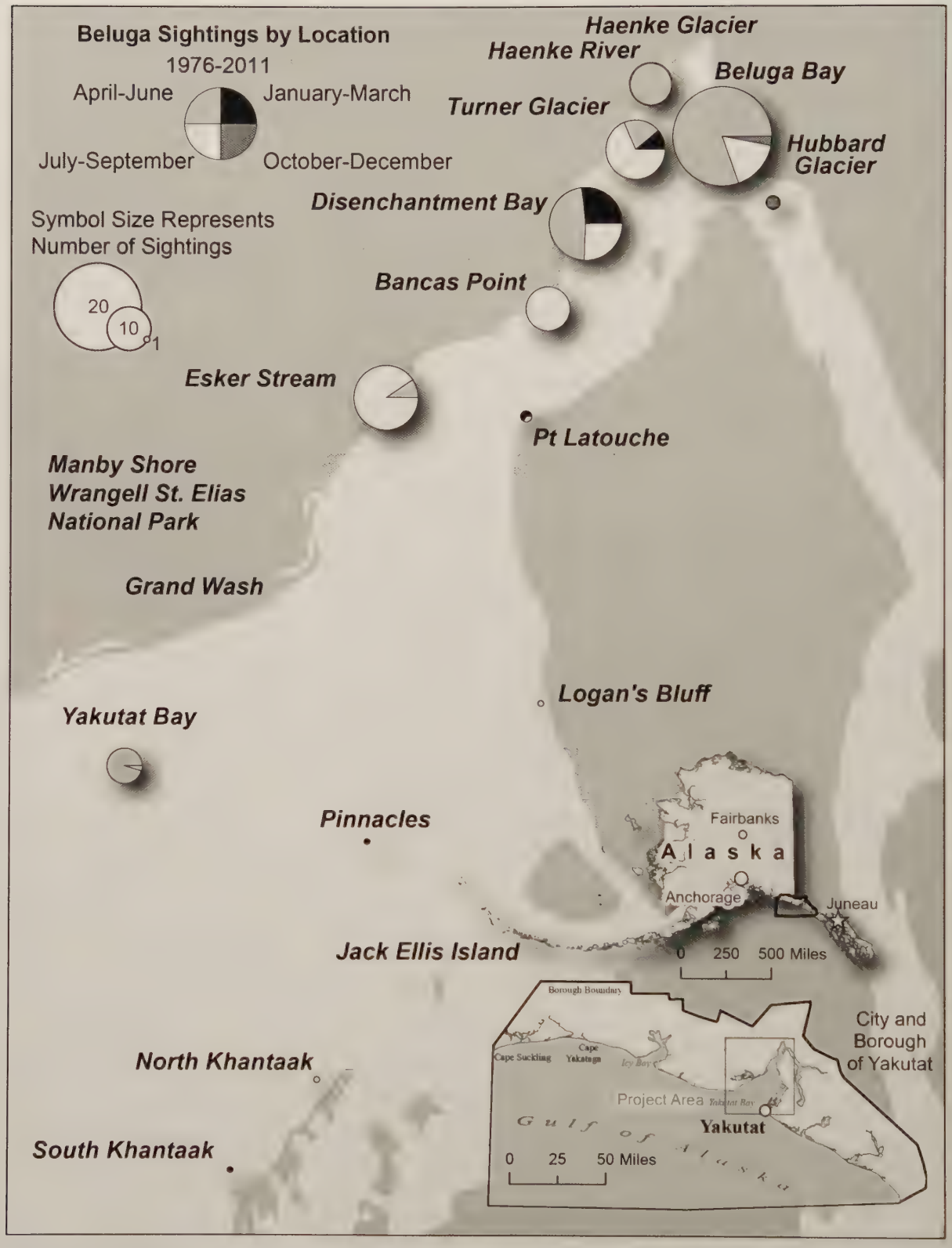

Figure 1.—Cumulative beluga sightings by season and location from 1938 to 2013. The size of the circle is representative of the number of sightings of belugas in the area.

ed since that time and it is unknown how this event has changed beluga movements.

During George's teenage years in the 1940's, hunting with his father and relatives in the spring, he heard the name for belugas; "That's how I got the [Tlingit] name [for belugas]...listen to [deceased Yakutat elders] Sampson Harry, Peter Harry, and William Thomas, and Oscar Frank. Kuyeedaayee [pronounced: cuu yee da yee]. I got that name from that old-timer [assuming Oscar Frank]." Although George was not certain, he believed the word for belugas was Tlingit rather than of Eyak origin. "I don't know if that is a Tlingit name....must be. Cause you know if they have a Tlingit name they been here...around here for years," George said.

Most sightings were in the area of Turner Glacier. "I don't see them along the beaches [of Bancas Point area]," said George. They have not been seen in the "open ocean" or very far from the western shore of Yakutat Bay. Nor have belugas been documented in Icy Bay, except once at the Point Riu spit in 1998. "I seen them way down...along here, indicating [Manby coast of Yakutat Bay]. But I never noticed any out here [middle of Yakutat Bay]. We were hunting seal we weren't looking for anything like that either, you know. Besides there was so much ice flow...you probably couldn't tell if it was beluga or iceberg." George had seen the belugas come out of Beluga Bay in the evening, then swim up Grand Wash. He did not offer any explanation for why the belugas might frequently swim up Grand Wash in the evening.

During the summer, while gillnetting at Manby and the west shores of Yakutat Bay with other fishermen, he said, "We used to go in this...Spoon River. Left our barge tied up there. We fished there ...but we never saw anything [belugas] down below [west of Spoon River]. We'd be there by... just getting dark and we'd go into Grand Wash and camp on the beach. Towards evening, they start coming in [to Grand Wash] and they go way up in [the river of Grand Wash]. We listen to them moaning and groaning all night there. Only time we saw them was when they're going up river. They come in there in the evening, and they start going up...I don't know when they get out. Probably get out before we wake up. They don't make noise when they are traveling. They'd come up, one right after the other, up the river though. But not schooled up, you know. Wish we had a camera then we could have taken pictures of them, never thought of that. They come right close. It's not very far across the river. Once they got inside, way up here, and you hear them; listening to them moaning and groaning. I don't know what they do up there. The way they sound, you know. It's a long ways, long ways from us but you could hear it real good."

George: "We used to see so much of them...Earnest Francis....sometimes he'd go with us, me and Sarge. He was so scared of them. He'd stick an oar in the water. He'd start pounding on it. He said it's going to get us. We [Tlingits] weren't afraid of them. Only Earnest, I guess [laughing]. We'd go right by them." George stated that he believed he saw more than 15–20 belugas at a time, while fishing and hunting in Yakutat Bay. When asked if he saw gray or black belugas, he said, "White. I didn't see any different colored ones. There might have been some, ones that I didn't see." In addition, George did not recall seeing any dead belugas stranded on the shore.

Around 1956, George left Yakutat to join the military. When he returned, fishing was better on other rivers, closing the chapter of his close encounters with belugas in Yakutat Bay. Looking back, he realized that Tlingits shared a quiet coexistence with belugas. Despite sharing food with the whales, such as Pacific salmon and herring, *Clupea pallasii*, Yakutat Tlingits are not known, according to current traditional knowledge, to have hunted or eaten belugas. When referring to the relationship with Yakutat belugas, Tlingits often said, "we left them alone and they left us alone."

Larry Powell and Byron Mallott

Informal discussions with Larry and Byron were held in Mallott's store. These two individuals fished as a team on the west side of Yakutat Bay in the 1970's. Larry felt that there were 20–30 whales on the Manby side when they fished near Esker Creek. Byron felt it was closer to 20.

Andrew Gray

Andrew is a lifelong commercial fisherman presently in his sixties and well respected in the community. He saw a dead beluga whale on Jack Ellis Island in the mid-1990's. He reported it, but the carcass was never located.

Overall, 53 beluga observations were recorded from scientific surveys compared with 13 reported from informal interviews and 3 were from the tribal meeting. Qualitatively, the elders meeting produced the earliest observation and the most cultural knowledge about the Yakutat beluga group. Locations of sightings were similar across all time periods.

Discussion

The earliest modern-day recollection of beluga whales was from George Valle, Jr., from 1938. Because the Tlingit had a name for belugas, "Kuyeedaayee," it would seem that they have been long-term residents of Yakutat. "Kuyeedaayee" did not have a direct translation; however, in discussions with native speakers, they felt the meaning to approximate "skin under the stars." Yakutat Tlingits are not known to have hunted or eaten belugas. During archeological survey work being conducted by the Yakutat Tlingit Tribe, David Ramos, Sr., and Kai Monture found a beluga skull with a single tooth, on North Khantaak Island in 2012. It is unknown if the skull is from a harvested animal or was beach cast and hauled into the forest by a grizzly bear, *Ursus arctos horribilis*. To understand its age and relation to the current beluga group, the skull was sent to Harbor Branch Oceano-

graphic Institute in 2013 in an attempt to extract DNA. Results are pending (O'Corry-Crowe).

Most beluga whale sightings were in the spring and summer in the Beluga Bay vicinity (Fig. 1). The only late fall–early winter sightings were near Turner Glacier. However, local fishing and hunting occurs predominantly from spring to fall; therefore, opportunistic sightings from fishermen, hunters, and airplane pilots are expected to be lower during wintertime. A recent acoustics monitoring study supports year-round presence of belugas in Yakutat Bay (Castellote et al., 2015). Similarly, recent genetic analysis indicates that these whales are likely endemic to the Yakutat Bay area and, while they are related to the Cook Inlet stock, they are genetically distinct from Cook Inlet whales (O'Corry-Crowe et al., 2015).

Both opportunistic and directed sightings are more common in Disenchantment Bay and from the northwest coast of Yakutat Bay to Manby Point. Less evidence of beluga presence has been reported for the eastern coast of Yakutat Bay despite this being the most heavily utilized area of the bay. A large gap in sightings between 1980 and 1992 is likely a product of historical high Pacific salmon prices and increased fishing effort on the eastern shoreline from the East Alsek River to the Situk River, reducing effort on the Manby side of Yakutat Bay.

Yakutat belugas seem to avoid open waters and stay close to ice, possibly to avoid predation by killer whales, *Orcinus orca*. Sighting distribution suggests that Disenchantment Bay might be their core habitat, with limited excursions to specific locations in Yakutat Bay, such as Grand Wash and Esker Creek, in particular along the west coast of the bay (e.g., Castellote et al., 2015). There are historical observations (George Valle) and more recent observations (gillnet incident) of belugas entering Grand Wash River and swimming upstream after Pacific salmon. This behavior might also happen in other rivers in Yakutat Bay (Pavlik observation from Dangerous River), as this is a common behavior in other resident beluga populations in Alaska (Rugh et al., 2000).

When belugas travel up river they are probably more susceptible to gillnet interactions due to the confined channels and potentially noisy soundscape. However, as the Manby shore has been gillnetted for decades, it is possible that the whales are familiar with nets as they appear to avoid them given the single known entanglement.

A total of six elders were formally interviewed regarding their knowledge regarding Yakutat beluga whales. Of these, three held the most knowledge. Ten commercial fishermen reported interactions with the whales, though only one involved entanglement. A total of 23 scientists and natural resource agency staff reported beluga observations and 3 commercial air taxi pilots.

Conclusions

Little is known about the present day population of Yakutat's belugas. What is certain is that they have been around since the early 20th century as indicated by George Valle's testimony and the fact that the native name, Kuyeedaayee, is still remembered. It is also apparent from these interviews that the population may have been larger in the past though there is no indication that this population has ever been large in comparison to other known stocks.

This TEK study should have been conducted years ago when George Valle's father and his peers were still alive. It is likely that the oral tradition regarding these whales was broken after the passing of that generation, and what remains are fragments of that knowledge. It is probable that this brief document has collected the majority of the remaining TEK available.

Acknowledgments

We would like to thank the U.S. National Park Service for generously funding both the elder's meeting and the services of Henry Huntington. Henry has invaluable experience in TEK and its application. We would also like to thank the following people for sharing their knowledge with us; George Valle, Sr., Rudy Pavlik, Mike Pavlik, George Ramos, Andrew Gray, Larry Powell, Byron Mallott, Johnny Pavlik, and John Matsko. John Jansen and Shawn Dahle, with the NMFS National Marine Mammal Lab, provided regular sightings of belugas during shipboard and aerial surveys for harbor seals.

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The Genetic Ecology and Population Origins of the Beluga Whales, *Delphinapterus leucas*, of Yakutat Bay

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ABSTRACT—Small populations or groups of individuals at the edge of a species' range can reveal much about a species' niche preference limitations, its demographic history, and its adaptive potential for range expansion or niche shifts. We investigated whether recent sightings of small numbers (n≤12) of beluga whales, Delphinapterus leucas, *in Yakutat Bay, Alaska, some 800 km distant from the nearest known population in Cook Inlet, represented a distinct group of whales or temporary extralimital movements from Cook Inlet, and if the former whether they exhibited any genetic consequences of small effective population size. Using remote biopsy sampling ($n_{samples}$=10), mtDNA sequencing, multi-locus genotyping, and PCR-based gender determination, we found that the Yakutat whales comprised both males and females, exhibited site fidelity across years, were significantly differentiated for mtDNA (F_{st} = 0.54, P < 0.0001) and microsatellite (F_{st} = 0.10, P < 0.0001) loci from the Cook Inlet population, and formed a distinct genetic cluster. Individual assignment methods identified Cook Inlet as the most likely origin of the Yakutat whales when compared to the four other population stocks in the western Nearctic: Bristol Bay, Norton Sound, the Chukchi Sea, and the Beaufort Sea (n = 494), but individual whales had low likelihoods of coming from Cook Inlet relative to whales sampled in that population.*

We developed a new exclusion-assignment method, GELATo, that estimates the likelihood of a group of whales arising within one, any, or none of a series of reference populations. Using the same five beluga whale reference populations we confirmed the close affinity of Yakutat to Cook Inlet but excluded the Yakutat group as likely immigrants from Cook Inlet (logL= -68.63$_{micros}$ and -63.06$_{mtDNA}$). These findings, in conjunction with recent beluga whale sightings, including young-of-the-year calves, in Yakutat Bay in all seasons, indicate a small, resident, reproductive group with limited current genetic exchange with Cook Inlet. Lower variation (H_{obs} = 0.580 v. 0.715) at neutral markers, significantly higher relatedness (mean difference in $r_{QeullerGt}$ = 0.410) among and inbreeding (mean difference in F = -0.1 to -0.19) within the Yakutat animals compared to Cook Inlet raise concerns about the loss of genetic diversity over time. While the small size and uncertain history and viability of the Yakutat group creates new management challenges, its location, unique habitat, and persistence up to now can provide insights into the survival of small groups on the warm edge of the species' range and is a testament to the effective stewardship of the local Tlingit community.

Introduction

Individuals on the frontier of a species' range typically define the geographic limits of suitable conditions for the maintenance of viable populations, but they can also represent the vanguard of a range or niche expansion or the relicts from past retreats. As such, groupings of individuals at the range edge can tell us much about a species' niche preference limitations, its demographic history, and its adaptability and potential for range expansion or shifts. It is for these reasons that range limits are receiving growing attention in the context of determining how species will face the increasing challenges of environmental and climate change (Gaston, 2009; Sexton et al., 2009, 2011).

The geographic range limits of species are often characterized by low population density (Jarema et al., 2009) where populations may be subject to the genetic and demographic consequences of small population size, including negative aspects of inbreeding (Hedrick and Kalinowski, 2000) and the Allee effect (Courchamp et al., 1999). In social species, these effects can be either compounded or alleviated by the size, genetic composition (e.g., kin- vs. nonkin-based), and breeding patterns of founding and immigrant groups. Furthermore, the extent of gene flow with larger central populations or other edge populations can influence the effective population size of marginal populations and the allelic variation upon which selection can act (Sexton et al., 2009, 2011).

Thus, determining the genetic origins of marginal populations, their genetic composition and breeding patterns, including levels of relatedness and inbreeding, and the extent of continuing genetic exchange with central populations can provide insight into the factors that influence the establishment and persistence of small groups or populations on the geographic frontier of a species' range. Such insight is key to predicting how species will respond to climate and other environmental change and has immediate application to assessing the viability of core populations, especially those experiencing declines and habitat loss.

Beluga whales, *Delphinapterus leucas*, have a nonuniform distribution across the Arctic and Subarctic (O'Corry-Crowe, 2008) shaped by

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doi: dx.doi.org/10.7755/MFR.77.1.5

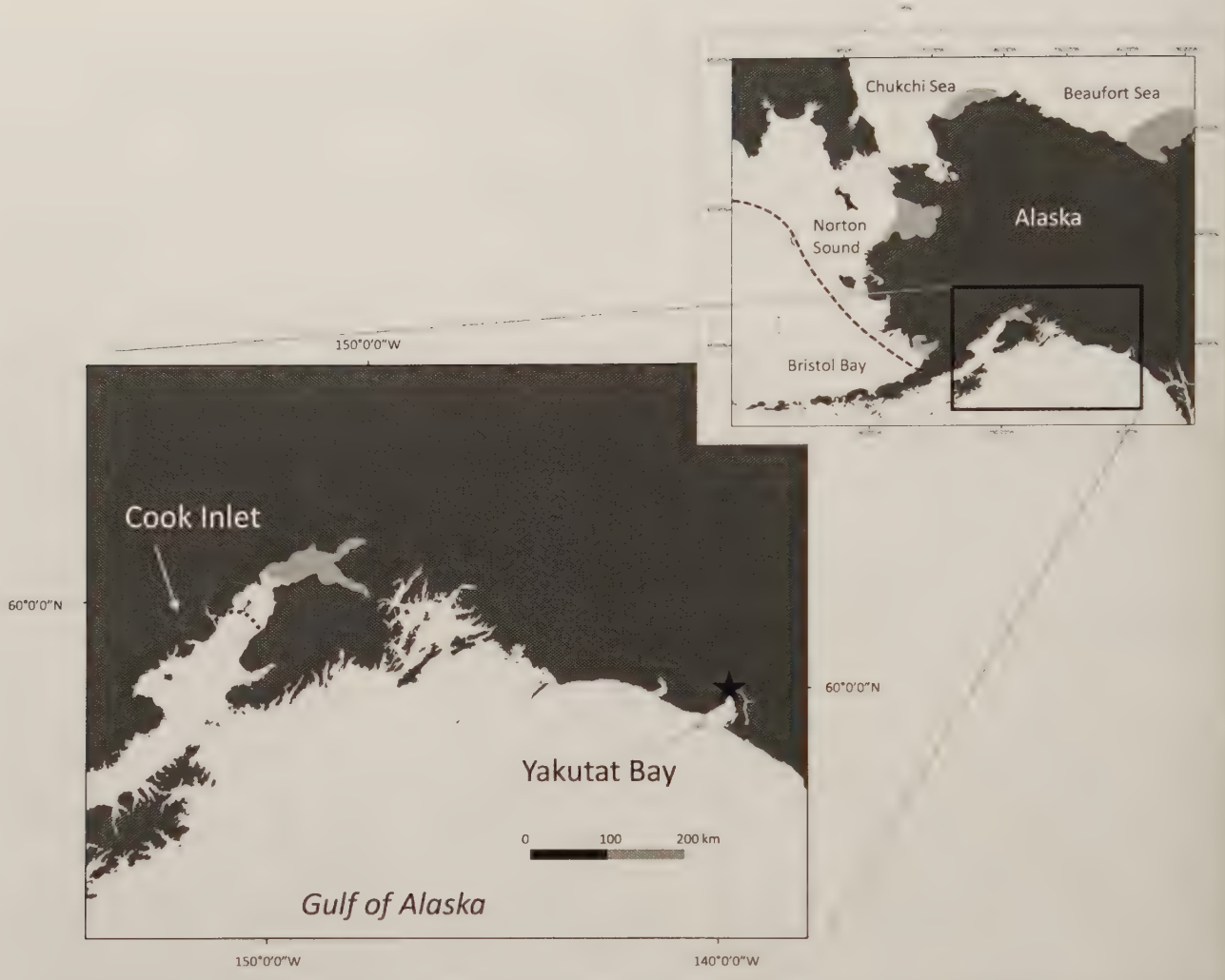


Figure 1.—Beluga whale distribution in the Gulf of Alaska. Primary summer and winter ranges are indicated by grey shading and a dotted black line. Insert is the summer distribution of beluga whales in the western Nearctic including year-round distribution in the Gulf of Alaska and the summer concentration areas in the Bering, Chukchi, and Beaufort seas (grey shading). The black dashed line represents median extent of winter sea ice.

glacial history, contemporary resource dispersion, physiological and physical constraints, and the behavioral tendency of this species to form social aggregations and return to traditional locations each year (Suydam et al., 2001; Lydersen et al., 2001; Laidre et al., 2008; Colbeck et al., 2013). Within the Gulf of Alaska, a small population of beluga whales is resident in the waters of Cook Inlet (Fig. 1; Rugh et al., 2000; Allen and Angliss, 2012). Satellite telemetry and sightings reveal that the population's current range is restricted to the mid and upper reaches of the inlet (Rugh et al., 2000; Hobbs et al., 2005). While dispersal cannot be completely excluded, this population of whales has been effectively geographically and genetically isolated from populations to the west and north for a long enough time that genetic divergence via drift is evident at neutral markers (O'Corry-Crowe et al., 1997, 2010).

The Cook Inlet population experienced dramatic declines in the 1990's, with an estimated reduction from 653 whales in 1994 to 347 whales by 1998 (Hobbs et al., 2000). This decline was accompanied by a northward contraction of population range within the inlet (Rugh et al., 2000, 2010). Subsequent research revealed that the population is not recovering but continues to decline at a much reduced rate of 0.6–1.6% per year (Lowry et al., 2006; Allen and Angliss, 2012; Hobbs et al., 2015). Its restricted range, low abundance, and apparent failure to recover following more than a decade of increased protection raise concerns over the viability of the Cook Inlet population (Allen and Angliss, 2012). Its geographic isolation and location on the warm edge of the species' range as well as its proximity to an increasingly urbanized region of Alaska add

concerns over the population's ability to respond to climate change and other challenges.

Over the past four decades periodic sightings of small numbers of beluga whales (typically ≤ 2) have been reported in the Gulf of Alaska outside of Cook Inlet (Harrison and Hall, 1978; Laidre et al., 2000; Calkins[1]). These records have been attributed to short-term extralimital movements by Cook Inlet animals (Laidre et al., 2000). One location, however, stands in stark contrast to the sporadic pattern of sightings in the rest of the gulf. Beluga whales, about 5–12 individuals, have been regularly reported in Yakutat Bay, some 700 km to the east of Cook Inlet and 800 km southeast of the contemporary range of the depleted Cook Inlet population (Fig. 1; Hubbard et al., 1999; Calkins[1]; O'Corry-Crowe et al.[2,3]). Further, traditional ecological knowledge (TEK) from the Yakutat Tlingit Tribe and local fishermen document consistent sightings of small groups (≤20) of beluga whales in the bay dating back to 1938 (Lucey et al., 2015).

Yakutat Bay is a deep glacial fiord fed by several tidewater glaciers at its head. A field study initiated in 2005 found that beluga whales selected habitats associated with actively calving glaciers that may reflect a unique ecology for this species in the North Pacific (O'Corry-Crowe et al.[2,3]). Furthermore, sightings over the past decade have occurred in all seasons and include adults, juveniles, and young of the year (Lucey et al., 2015).

The evidence to date may indicate that beluga whales regularly move between Cook Inlet and Yakutat Bay, and that the current whales are recent visitors or colonizers from Cook Inlet, possibly even a single family group. Such scenarios would potentially extend the known range and habitat of the endangered Cook Inlet population. Alternatively, these findings raise the possibility of the persistence of a very small reproductive group or population of whales in a previously unknown location and unique habitat beyond the known southern limit of the species' range.

Determining the genetic origins of the Yakutat whales, their breeding patterns, and level of kinship and inbreeding, and the extent of continuing gene flow with the likely source population, Cook Inlet, will provide critical insight into: 1) the relationship between Yakutat Bay and Cook Inlet, and 2) the viability of populations of beluga whales at the warm edge of the species' range. This is essential to modeling the future prospects of the larger Cook Inlet population already struggling to recover from recent declines. We conducted such a study and present our findings here. Using remote tissue biopsy methods, multi-locus genotyping, and a suite of moment and likelihood-based statistical analyses, including a new group exclusion-assignment test (GELATo) we introduce here, we addressed the following:

1) Is there evidence of long-term use of Yakutat Bay by individual whales?
2) Do the Yakutat whales have a lower neutral genetic diversity than similar sized sample sets from the Cook Inlet population?
3) Are Yakutat whales, on average, more related or inbred than whales sampled in Cook Inlet?
4) As a group, are the Yakutat whales likely to originate from Cook Inlet and or any other reference population?
5) Are individual Yakutat whales likely to be immigrants from Cook Inlet or any of the other populations of beluga whales in Alaskan waters?

Methods

Skin plug samples were collected from free-swimming belugas in Yakutat Bay, Alaska, via remote biopsy between 2002 and 2008. Tissue was preserved in 20% DMSO-NaCl solution and archived at -20°C. Total DNA was extracted from each tissue sample by established protocols and screened for variation within 410bp of the mtDNA control region and 8 independent microsatellite loci according to previously published methods (O'Corry-Crowe et al., 1997, 2010). The gender of each sample was also determined by PCR-based methods (Fain and LeMay, 1995), and replicate genotyping, sequencing, and gender determination was conducted to confirm genetic scores.

Permutation-based estimation of observed heterozygosity (H_o) and cumulative probabilities of identity (P_{ID}), as well as calculation of the total number of alleles across all loci were conducted using the program Doh (Brzustowski, 2002). To compare estimates of such genetic parameters between Yakutat and similar-sized sample sets from another population we used a customized script written in Access, Go-Random[4] (Beaman and O'Corry-Crowe[5]) to generate multiple subsets of samples of equivalent magnitude chosen at random from the population's sample set. MCMC exact tests (500,000 iterations) were used to test for deviations from Hardy-Weinberg expectations and levels of genetic differentiation at both microsatellite and mtDNA loci using Genepop 4.1 (Rousett, 2008). *F* statistics were also performed in Genepop.

Considering the small sample size from Yakutat (see below), we used POWSIM 4.1 (Ryman and Palm,

[1]Calkins, D. G. 1983. Marine mammals of lower Cook Inlet and the potential impact from outer continental shelf oil and gas exploration, development and transport. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 20:171–265

[2]O'Corry-Crowe, G, W. Lucey, C. Bonin, E. Henniger, and R. Hobbs. 2006. The ecology, status and stock identity of beluga whales, *Delphinapterus leucas*, in Yakutat Bay, Alaska. Rep. to U.S. Mar. Mamm. Comm., NMFS-YSB-YTT, 22 p.

[3]O'Corry-Crowe, G., W. Lucey, M. Castellote, and K. Stafford. 2008. Abundance, habitat use and behavior of beluga whales in Yakutat Bay, May 2008, as revealed by passive acoustic monitoring, visual observations and photo-id. Final Rep. to Prot. Resour. Div., Alaska Reg. Off., NMFS. NOAA, 49 p. (Available at: http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/yakutat/yakutat_2008belugas_0309.pdf).

[4]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[5]Beaman, N., and G. O'Corry-Crowe. Harbor Branch Ocean. Inst., Fla. Atl. Univ., 5600 U.S. 1 North, Fort Pierce, FL 34946.

2006; Ryman, 2011) to assess statistical power and estimate type 1 error in the data when testing for genetic differentiation. Using the observed allele frequencies we ran simulations (n= 200 and 1,000 runs) for a range of sampling regimes (n1 and/or n2 = 5 to 100) to determine the minimum sample sizes required for two standard tests (chi-square and Fisher's exact) to correctly reject the H_o of homogeneity for a range of expected divergence levels (F_{st} = 0.01, 0.05, 0.1, or 0.2) that include the observed estimate. Type 1 (α) error was estimated by running simulations under conditions of no differentiation (F_{st}=0) and counting the proportion of runs that rejected the H_o when it was true. To determine whether some of the biopsy samples were recaptures of the same individual we conducted genetic identity analyses using Cervus 3.0 (Kalinowski et al., 2007). Pairwise probabilities of identity (P_{ID}) were estimated from the multi-locus genotypic data, and exact matches with low P_{ID} relative to the likely abundance of whales in Yakutat were considered re-captures of the same individual.

Genotyping errors can influence mark-recapture analysis by erroneously detecting a mismatch (Kalinowski et al., 2006). We used more extensive data (n=547 samples) from a recent genetic mark-recapture study on beluga whales conducted in our lab to estimate genotyping error rates and their potential role in mismatches. Genetic inbreeding (F) and relatedness (r) among pairs of individuals, and within and among groups of whales were investigated using COANCESTRY (Wang, 2011). Two maximum-likelihood (Milligan, 2003; Wang, 2007) and one moment (Queller and Goodnight, 1989) estimator of r and two moment (Ritland, 1996; Lynch and Ritland, 1999) estimators of F coefficients were calculated using multi-locus genotypic data. The ML methods account for genotyping errors and for inbreeding by including all estimated probabilities of identity-by-decent across pairs of alleles, including alleles within individuals (Wang, 2011). Bootstrap resampling (10,000 reps) was used to test significance in mean r among groupings and mean F within individuals. Data from 78 whales sampled from Cook Inlet were used in some of these analyses.

We used assignment methods and genetic data from five reference populations of beluga whale in Alaska waters, including the Cook Inlet population, (Cook Inlet, Bristol Bay, Norton Sound, Chukchi Sea, and Beaufort Sea, n=494) (O'Corry-Crowe et al.[6]) to determine the likely origins of the Yakutat whales. Individuals were assigned to populations based on estimated likelihoods of their genotype and mtDNA haplotype arising in each of the sampled populations under assumptions of random assortment of alleles and independence of loci (Paetkau et al., 1995; Banks and Eichert, 2000). Analyses of diploid and haploid data were conducted separately as well as combined using the WHICHRUN 4.1 program (Banks and Eichert, 2000).

We used the Bayesian model-based clustering method, STRUCTURE 2.3.4 (Pritchard et al., 2000, 2010), to estimate the likely number of genetic clusters or populations, K, in the Gulf of Alaska dataset (Yakutat and Cook Inlet) and to assign individuals to cluster of origin. Multiple MCMC runs (50,000 burn-in followed by 10^6 iterations) of the data for a range of values of k were conducted for both admixture and no admixture ancestry models. To accommodate possible limited information content (i.e, due to small n, low divergence) on structure in our dataset for this algorithm, we also applied the LOCPRIOR option that uses information on sampling location as an unbiased informative prior (Hubisz et al., 2009). We also used the non-MCMC, iterative method, FLOCK 3.1 (Duchesne et al., 2013) to estimate the number of populations, K, and allocate individuals to those populations (Duchesne and Turgeon, 2012). To assess the method's ability to accommodate limited information content on structure in the data, we conducted a series of trials (each with 20 runs X 50 iterations) on two genetically differentiated populations (K=2, Bristol Bay and Cook Inlet) varying sample size with each trial.

We also used GENECLASS2 (Piry et al., 2004) to assign or exclude reference populations as the origin of individuals or groups of individuals. Employing the Bayesian and frequency-based criteria of Rannala and Mountain (1997), Baudouin and Lebrun (2000), and Paetkau et al. (1995) log likelihood ratio scores ($Score_{i,T}$) were used to assign likely population of origin (highest rank score) and exclude other populations (rank score falls below a predetermined threshold, e.g. $Score_{i,T}$ <0.5). Furthermore, MCMC methods were used in a semi-Bayesian exclusion procedure where observed probabilities of test samples were compared to those of simulated samples (n=1,000 to 10,000) from each population (Cornuet et al., 1999, Baudouin et al., 2004).

In determining whether a test group of individuals comes from one, any, or none of a series of reference populations, however, the approach used in GENECLASS2 has a series of shortcomings. By only considering relative likelihoods among a series of reference populations, the logL methods do not estimate genotypic (or haplotypic) likelihoods of test groups relative to those of other similar sized groupings within each population, while the MCMC methods tend towards excessive exclusion of reference populations (see Discussion). We therefore developed a test that estimates these relative likelihoods and improves exclusion accuracy (Group ExcLusion-Assignment Test – GELATo). Specifically, we addressed the following question: "assuming the whales sampled in Yakutat Bay were from a single group or population, were any of the reference populations sampled the likely source, and if so which was the most likely?"

[6]O'Corry-Crowe, G., R. Suydam, L. Quakenbush, B. Mahoney, L. Harwood, W. Goodwin, K. Frost. 2015. Beluga whale population structure, dispersal and breeding patterns in a changing Arctic. Harbor Branch Ocean. Inst., Fla. Atl. Univ., unpubl. rep., 26 p.

Table 1.—Field and gender information on biopsy samples of beluga whales in Yakutat Bay, Alaska. Age was estimated based on size and color. Gender was determined via PCR.

Field ID	Date of sample collection	Age/Color	Gender	Sampled while in a group
DL-YK-01-2	20 Sept. 2002	Adult/White	F	yes
DL-YK-03-928	28 Sept. 2003		M	–
DL-YAK-1-04	01 May 2004		F	–
DL-YAK-2-04	01 May 2004		M	–
DL-YAK-05-1	19 May 2005	Adult/White	M	yes
DL-YAK-05-2	19 May 2005	Adult/White	M	yes
YAK-1A-07	04 Aug. 2007		F	–
DL-YAK-08-1	16 May 2008	Juvenile/Grey	M	yes
DL-YAK-08-2	19 May 2008	Juvenile/Grey	F	yes
DL-YAK-08-3	19 May 2008	Adult/White	M	yes

GELATo is a permutation-based test that compares the distributions of F_{st} values for a population of unknown origin to potential source populations with null F_{st} distributions generated from comparing similarly sized random samples from the source populations back to themselves. For a given "unknown" population, *U*, with a sample size of N_u, the likelihood of its membership to a given source population, *K*, is calculated as follows. A random sample of N_u individuals is selected from *K* without replacement (K_u). These individuals are used to calculate an F_{st} value from the null distribution (F_{st} *-null*) by comparing them to the remaining individuals in *K* ($K_{k'}$). An "observed" F_{st} (F_{st} *-obs*) is then calculated between all individuals from *U* and $K_{k'}$. This process is repeated 1,000 times to generate a distribution of F_{st} *-null* and F_{st} *-obs*. The null distribution is then modeled as a Normal distribution with the mean and standard deviation of F_{st} *–null.*

The likelihood that *U* came from *K* is the product of the likelihood (sum of log-likelihoods) of all values in F_{st} *–obs* given the fitted null distribution. The probability that population *U* came from *K* is its likelihood of F_{st} *–obs* given the null for *K* divided by the product of likelihoods to each potential source population. In the results below, we express the likelihoods as deviations of the log-likelihood from the maximum observed log-likelihoods. As can be seen, this method can also be used as an exclusion test, where low likelihoods (negative log-likelihoods) for all source populations would indicate that the test group was either of mixed origin, a nonrandom sample from one of the source populations, or from an unsampled population.[7]

Results

A total of 10 skin biopsy samples were collected from free swimming beluga whales in Yakutat Bay, Alaska, between 2002 and 2008. PCR-based tests found similar proportions of males and females in the sample set (Table 1).

Genetic Identity Analysis

The genetic identity analysis revealed that of the 45 pairwise comparisons involving the 10 samples across 8 microsatellite loci, two dyads differed at one allele in one locus (locus D3 in both cases), while all others differed by multiple alleles at two or more loci. Reanalysis revealed that both single allele differences were the result of genotyping error. An independent assessment of genotyping error rates in a large dataset from Bristol Bay (n=547) found that single allelic differences at one of eight loci were likely the result of a genotyping error, while differences at two or more loci reflected real differences among individuals (O'Corry-Crowe et al.[8]). This has also been found in other species for as few as six loci (Kalinowski et al., 2006).

Our findings indicate that the two exact matches represent two cases of genetic recapture. Finally, the complete removal of locus D3 resulted in estimated pairwise P_{ID} orders of magnitude lower (2.72×10^{-3} and 1.01×10^{-5}) than probable whale abundance in Yakutat further indicating that two whales were resampled during the course of the study. The first case involved a male whale, DL-Yak-2-04, initially sampled on 01 May 2004 and resampled a year later on 19 May 2005. The second case involved a female whale, DL-Yak-1-04, biopsied on the same day as the initial sampling of DL-Yak-2-04 and subsequently resampled 3 years and 3 months later on 04 Aug. 2007. These findings establish for the first time the occurrence of individual whales in Yakutat Bay across multiple years.

Genetic Diversity and Differentiation

Only one mtDNA haplotype, Haplotype 2, was documented in all the Yakutat animals. Haplotype 2 is present within Cook Inlet at moderate frequencies (14%) but is not the most common lineage in this population. This haplotype has also been found in Norton Sound (0.52%), the Chukchi Sea (47%), and the Beaufort Sea (5.6%) (O'Corry-Crowe et al.[8]). Excluding recaptures (see below), average heterozygosity per nuclear locus for Yakutat ranged from 0.25–0.875, and no loci were found to deviate from Hardy-Weinberg expectations ($p > 0.136$).

The Yakutat whales were found to have lower mean levels of heterozygosity (H_{obs} = 0.580 vs. 0.715), lower numbers of alleles (total allele count = 22 vs. 36.3), and higher estimated cumulative probabilities of identity-by-descent ($P_{ID} = 3.24 \times 10^{-5}$ vs. 2.92×10^{-8}) than sets of samples (n=50) of similar magnitude drawn at random from the Cook Inlet population (Fig. 2). Even when the Cook Inlet resampling (n=25 sets) was restricted to individuals with the same mtDNA haplotype, the diversity indices were still lower and P_{ID} higher for the single-matriline group in Yakutat Bay compared to Cook Inlet (Fig. 2).

[7]All code for GELATo was written in R v2.15.2 (R Core Team 2012) by FIA, and is available on request.

[8]O'Corry-Crowe, G., J. Citta, and L. Quakenbush. 2012. Genetic mark-recapture study of beluga whales in Bristol Bay, Alaska: 2002–2011. Harbor Branch Ocean. Inst., FAU, 10 p.

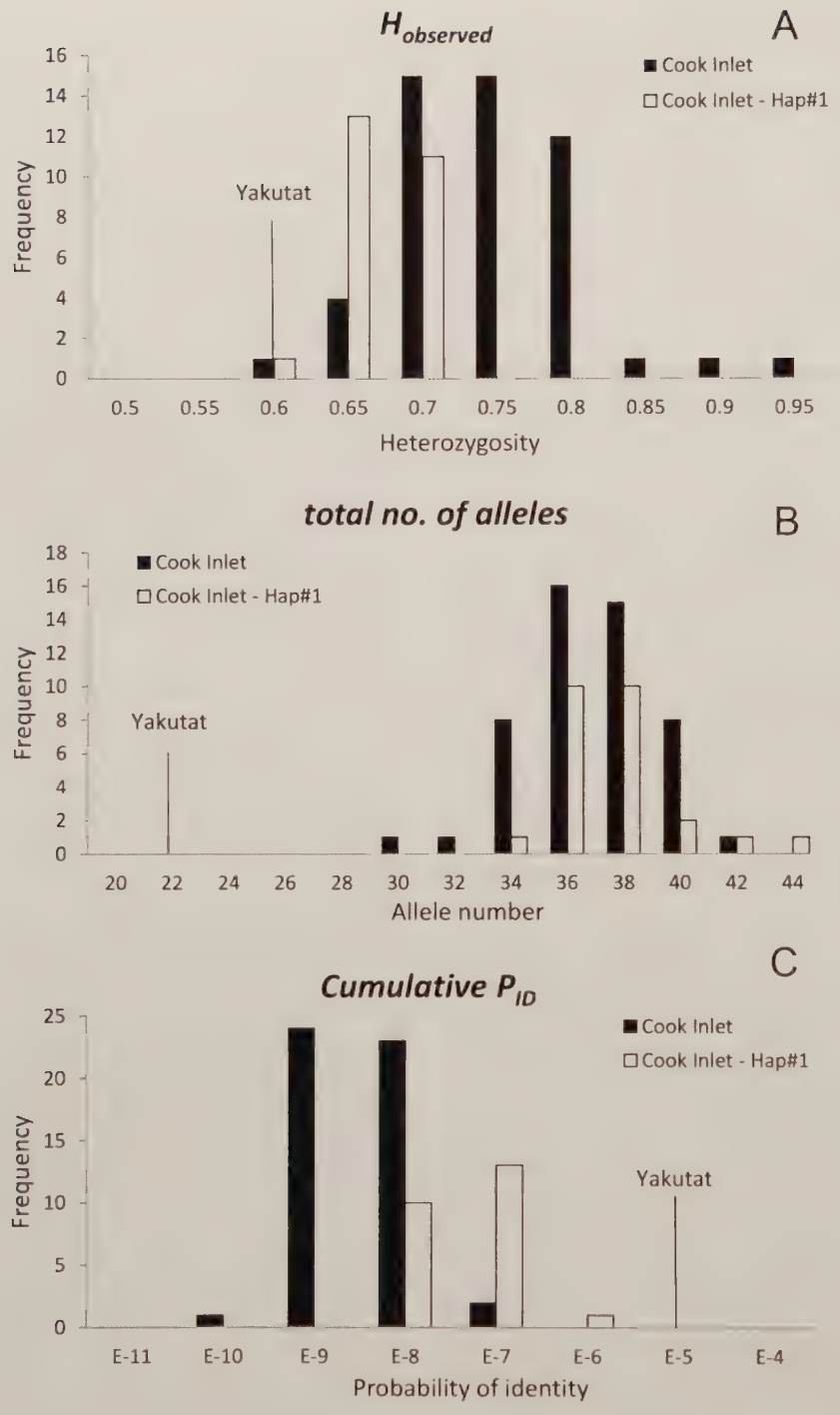


Figure 2.—Microsatellite diversity in beluga whales from Yakutat Bay compared to Cook Inlet and a single matriline within Cook Inlet; A) mean observed heterozygosity across all loci, B) the cumulative total number of unique alleles, C) estimated probability of identity by descent across all loci. Black bars represent the distribution of estimates for Cook Inlet based on 50 random draws of 8 individuals from the Cook Inlet data set. White bars represent the distribution of estimates for Cook Inlet based on 25 random draws of 8 individuals from one matriline (Hap#1) within the Cook Inlet data set. Black line represents estimate from Yakutat Bay based on the 8 individuals sampled.

The Yakutat sample set was significantly differentiated from Cook Inlet for both microsatellite loci (F_{st} = 0.106; P = 0.065 - 0.0001) and mtDNA (F_{st} = 0.536; $P <$ 0.0001). The POWSIM analysis revealed that the eight microsatellite loci used had sufficient power to provide a 99% probability of detecting an F_{st} as low as 0.05 for the nuclear data when analyzing skewed sample sizes of 8 and 78 for pop1 and pop2 (i.e., Yakutat Bay and Cook Inlet sample sizes) and yielded a type 1 error close to 0.05 (α = 0.03 – 0.08).

Inbreeding and Relatedness

All three estimators of relatedness yielded similar results although ML methods tended toward higher r values for pairs of highly homozygous individuals with few differences. When the entire Gulf of Alaska (i.e., Cook Inlet and Yakutat Bay) was treated as a single population, the highest estimated relatedness for all estimators was found among pairs of Yakutat whales with many in excess of r = 0.3 (Fig. 3a). Average relatedness among beluga whales within Yakutat was significantly higher than among whales within Cook Inlet (e.g., observed difference in mean $r_{QeullerGt}$ = 0.410, which lies well outside the 99% confidence intervals of the bootstrap analysis, Fig. 3b). Furthermore, average relatedness within Yakutat was significantly higher than average relatedness between Cook Inlet and Yakutat whales (e.g., observed difference in mean $r_{QeullerGt}$ = 0.418, which lies well outside the 99% confidence intervals of the bootstrap analysis, Fig. 3c).

The Yakutat whales were also found to have higher inbreeding coefficients, on average, than whales in Cook Inlet. Significance tests differed among the two estimators with the observed difference falling outside the 95% confidence intervals of the bootstrap analysis for the Lynch and Ritland estimator and inside for the Ritland estimator. Restricting the estimated allelic frequencies to include only Yakutat whales, average dyadic relatedness coefficients were lower but close relationships ($r > 0.4$) were still evident.

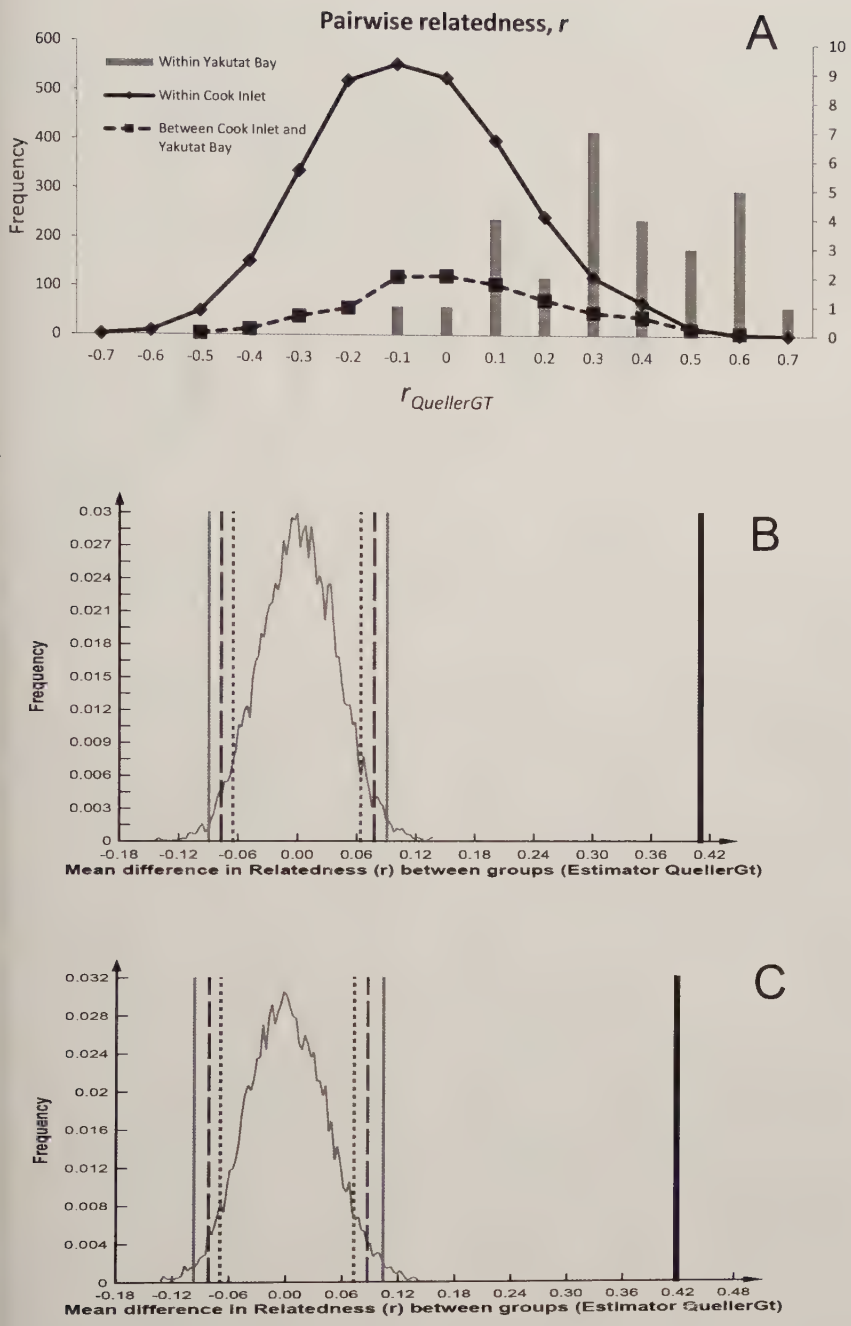


Figure 3.—Estimated relatedness (r) in Yakutat Bay compared to Cook Inlet beluga whales using COANCESTRY: A) pairwise estimates of r using the Queller and Goodnight estimator, B) mean difference in r within Yakutat compared to within Cook Inlet whales, and (C) mean difference in r within Yakutat compared to between Yakutat and Cook Inlet. If the observed difference (black line) falls outside the 90% (dotted lines), 95% (dashed lines), and 99% (grey lines) confidence intervals from the bootstrap analysis distribution the difference is adjudged to be significant

Assignment and Exclusion Tests

Using the assignment criteria in GENECLASS2, all eight Yakutat whales had the highest likelihood of arising within the Cook Inlet population. However, most of the Yakutat whales' assignment likelihoods to Cook Inlet fell within the lower range of likelihoods observed for Cook Inlet animals assigned to their own population. The remaining Yakutat whales had lower likelihoods (Fig. 4). This pattern was also observed with WHICHRUN, including tests that used microsatellite and mtDNA data combined. These findings indicate that while the likelihood of encountering each of the Yakutat whales' multilocus genotype in a given reference population is highest for the Cook Inlet population, most of the Yakutat genotypes have relatively low likelihoods of arising in the Cook Inlet population.

The STRUCTURE analyses where information on sample location was not used to assist clustering outcomes did not provide a clear signal of structure in the Gulf of Alaska dataset. When structure was apparent (i.e., $k \geq 2$), the Yakutat whales always clustered together. When prior information on sample origin was included, the most likely number of genetic groups was $K = 2$ (i.e., $\Pr(K \mid X) \approx 1$). These two groupings corresponded unambiguously to Yakutat and Cook Inlet for both admix and noadmix ancestry models with all individuals from Yakutat assigned to one cluster and all individuals from Cook Inlet assigned to the other (Fig. 5).

The FLOCK analysis identified $K = 2$ genetic groups (PL $\geq$ 6), allocated the Cook Inlet samples across both groups, and allocated all the Yakutat whales to one of these groups. The trials involving Bristol Bay and Cook Inlet found that with moderate to large sample sizes (n$\geq$20) FLOCK performed well (i.e, estimated $K = 2$, allocated >80% of individuals to their sampled population). By contrast, when the sample size from even one location was lowered to values on the order of n=10, FLOCK rarely yielded pla-

teau sequences that were long enough (i.e., PL ≥ 6 for a run number of 50) to estimate K with confidence (i.e., yielded an "undecided" verdict). Furthermore, a substantial number of individuals from either population were miss-assigned.

The analytical group assignment tests in GENECLASS2 all assigned the Yakutat whales to Cook Inlet. The assignment criterion, $-\log_{10}(L)$, was lowest for Cook Inlet and the score for the Yakutat group of individuals, $Score_{Yak}$ = 100%. By contrast, the MCMC resampling procedure in GENECLASS2 gave the opposite result: Yakutat as a group was excluded from Cook Inlet. Further analysis, however, revealed that this test consistently "excluded" subsets of individuals from their own reference population when tested as a group (see Discussion).

The group exclusion-assignment test, GELATo, revealed that while the Yakutat whales have the strongest affinity with Cook Inlet, as a group they have a very low likelihood (negative Log$L$) of coming from Cook Inlet (Fig. 6). The test excluded the Yakutat whales from all baseline populations including Cook Inlet for both the microsatellite (Log$L$ = -68.63 to -268.6) and the mtDNA (Log$L$ = -17.29 to -106.1) data. The Yakutat sample set did have a relatively high, but still negative, likelihood (lnL = -17.3) of being sampled in the Chukchi Sea based on mtDNA due to the relatively high occurrence of Hap#2 (47%) in that population (O'Corry-Crowe et al., 1997, 2010).

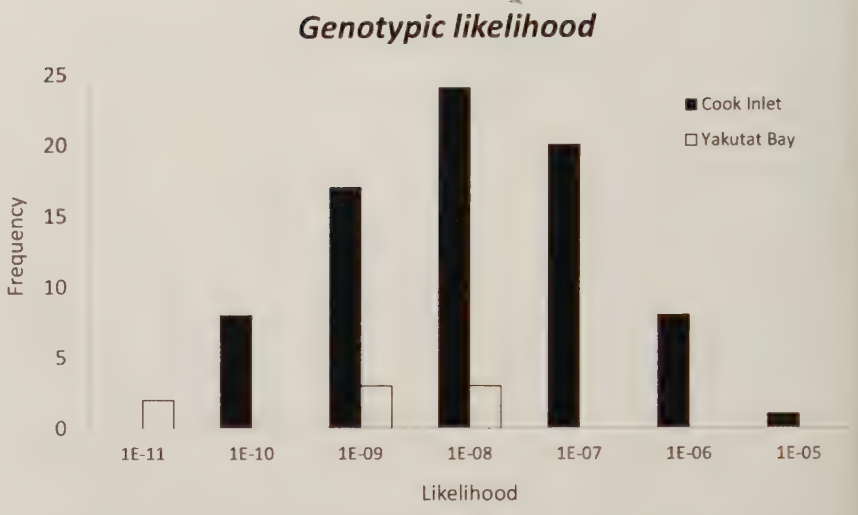


Figure 4.—Multilocus genotypic likelihoods of individual Yakutat whales (white bars) arising in the Cook Inlet population compared to the likelihood of whales sampled in Cook Inlet (black bars), estimated in GENECLASS2. Results from the analysis using the Bayesian assignment criterion of Rannala and Mountain (1997) are presented here.

Discussion

The genetic analysis of beluga whales sampled in Yakutat Bay between 2002 and 2008 revealed that the whales in this glacial fjord system, recently estimated to number less than 20 individuals (Lucey et al., 2015), are unlikely to represent recent arrivals or seasonal visitors from the Cook Inlet population to the northwest. The Yakutat whales do not appear to experience substantial contemporary genetic exchange with the larger Cook Inlet population. Further, the genetic "re-sights" of the same individuals across years, when taken with recent sightings of beluga whales in all seasons, including juveniles and young-of-year calves (Hubbard et al., 1999; O'Corry-Crowe et al.[2,3]) and TEK of beluga whales in this region spanning 80 years (Lucey et al., 2015) indicate that the Yakutat beluga whales likely represent a small, resident reproductive group of whales on the southern edge of the species' range.

High average relatedness among the Yakutat whales combined with higher inbreeding coefficients and lower heterozygosity and allelic (and haplotypic) diversity relative to the Cook Inlet population indicate that this group may be exhibiting negative genetic consequences of low abundance and genetic isolation.

The use of a broad suite of complementary methods of genetic analysis, including a power analysis and a new group-based assignment/exclusion method, revealed that genetic data from a relatively small number of samples was sufficient to address a number of key questions. Individual likelihood-based assignment methods identified Cook Inlet as the most likely origin of Yakutat whales when compared to other baseline populations. It does not necessarily follow, however, that the Yakutat whales were primarily resident in, or had recently immigrated from Cook Inlet. Rather, the low individual likelihoods of many Yakutat genotypes occurring in Cook Inlet (relative to Cook Inlet whales) suggest that Yakutat Bay whales have Cook Inlet ancestry but may not have been born in Cook Inlet. Estimates of relatedness and inbreeding revealed that the Yakutat sample set was not a random sample from the entire Gulf of Alaska and that preferential interbreeding among the Yakutat whales has led to high levels of relatedness among group members, and slightly higher average inbreeding within individual whales.

A number of widely different approaches found that the Yakutat whales, as a group, were genetically distinct from Cook Inlet. F statistics and homogeneity tests revealed substantial and statistically significant differentiation between Yakutat and Cook Inlet, STRUCTURE identified Yakutat as its own distinct genetic cluster, and GELATo excluded Yakutat as unlikely to occur in Cook Inlet or any other population studied. The close affinity of Yakutat to the Chukchi Sea in

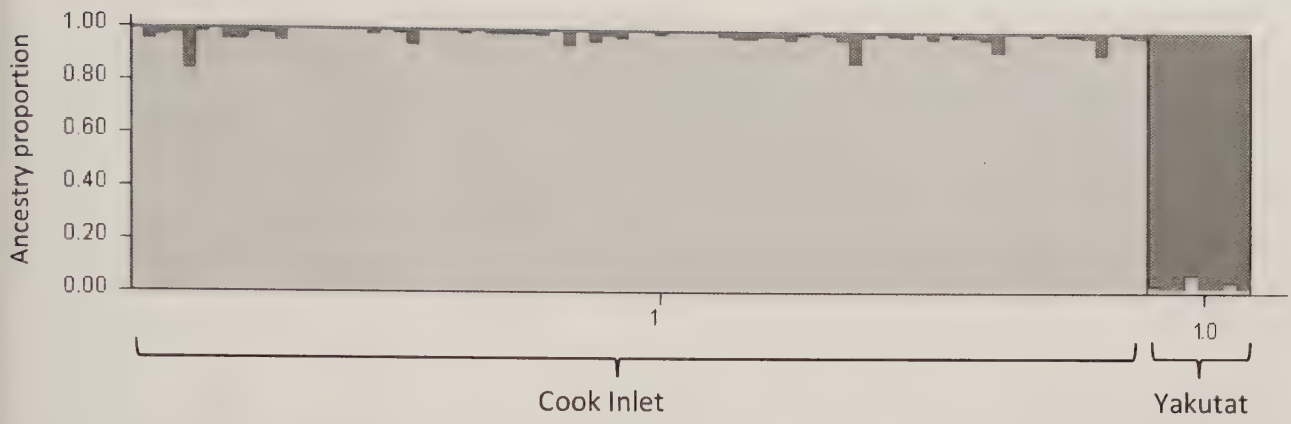


Figure 5.—Inferred membership in K=2 genetic clusters from a STRUCTURE analysis of all Gulf of Alaska beluga whale samples. The summary plot is for the analysis that allowed admixture and used the LOCPRIOR option. Each individual is represented by a single vertical line broken into K colored segments, with lengths proportional to membership in each of the K inferred clusters.

the GELATo mtDNA analysis differed markedly from that for the multilocus microsatellite analysis. This is likely due to the demographic history of the maternally inherited mtDNA that has resulted in the wide distribution of Hap#2 across much of the species' range rather than contemporary dispersal between Yakutat and the Chukchi Sea, and cautions against relying on a single marker for assignment- or allocation-based tests.

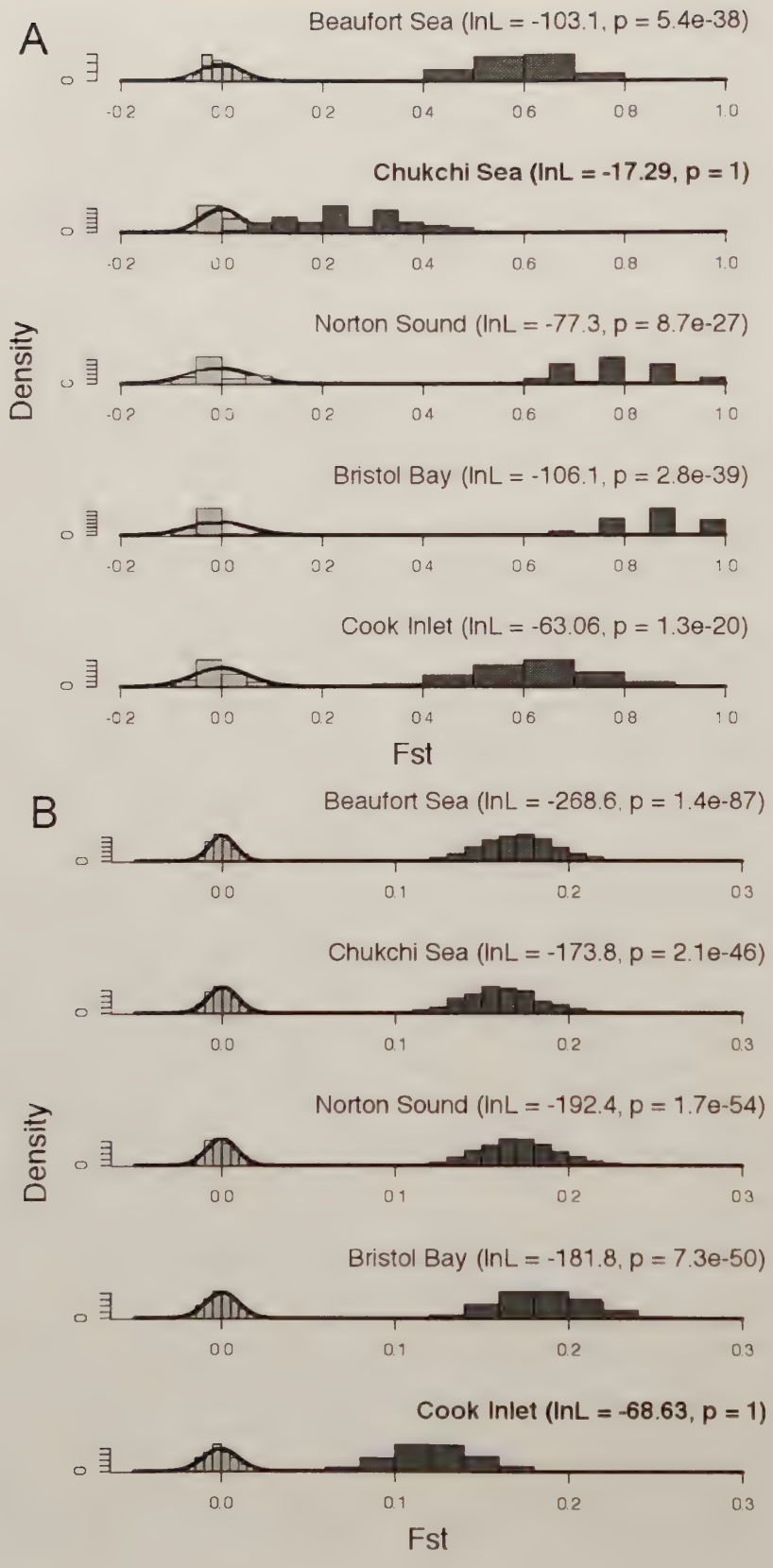
The group assignment criteria of Paetkau et al. (1995, 2004), Rannala and Mountain (1997), and Baudouin and Lebrun (2000) as implemented in the GENECLASS2 (Piry et al., 2004) program all estimated the highest likelihoods of the Yakutat whales coming from Cook Inlet, each giving a rank score of 100% to this population. In all three methods the assignment criterion is simply the highest estimated likelihood (rank score) while the exclusion criterion is an arbitrary rank score value below which it is considered that population-of-origin is unlikely (Piry et al., 2004).

These criteria, however, do not provide any insight into whether the group of whales tested is in fact likely or unlikely to occur in each of the reference populations. To illustrate this, we tested subsets of whales similar in magnitude to that of the Yakutat test group (i.e., n=8) from the genetically isolated Cook Inlet population against the four remaining reference populations in Alaska and Northwest Canada. Earlier studies had found negligible levels of contemporary gene flow between Cook Inlet and these four populations and that all individuals tested here had the highest likelihoods of arising within Cook Inlet (O'Corry-Crowe et al.[6]). And yet, in all individual and group assignment tests in GENCLASS2, the Cook Inlet whales were assigned to one of the other populations, some with rank scores > 80% (not shown). Similarly, using an exclusion criterion based on a rank score can only exclude the lowest scores (as long as they fall below the threshold, e.g., 0.05%) but cannot exclude all populations. This is a problem if the test group is from none of the reference populations.

The method we present (GELATo) overcomes both of these limitations. The assignment and exclusion criteria are based on the likelihood of the test group relative to randomly chosen groups of individuals (of similar magnitude) from each population. The tests are conducted on each reference population independently and rank scores are not relied upon. Strong overlap between the population distribution (based on resampled replicates of the original reference dataset) and test group distribution (based on observed differences between the test group and resampled reference population) indicates a high likelihood of the group coming from that population, while non-overlapping distributions excludes the group.

A further shortcoming of the exclusion methods in GENECLASS2 is that while the rank-score methods tended to under-exclude populations, the MCMC methods (Rannala and Mountain, 1997; Cornuet et al., 1999; Paetkau et al., 2004) tended to do the reverse, excessively exclude populations that were in fact the real origin of the test group. We determined this by running a series of tests in GELATo and GENECLASS2 where 100 "groups" of individuals (n=8) were randomly subsampled from their own population (e.g., Cook Inlet, Chukchi Sea). In all cases the former approach correctly assigned these groups to their population whereas the MCMC methods almost always excluded (probability < 0.05) groups numbering three or more individuals.

Our method, as with all other group methods, assumes random associations of individuals and random breeding among group members, which may not hold for small groups of beluga whales. Beluga whales are highly social, characterized by a wide variety of grouping patterns. If such grouping behavior is kin-based, it is possible that a small group of closely related


A
Beaufort Sea (lnL = -103.1, p = 5.4e-38)
Chukchi Sea (lnL = -17.29, p = 1)
Norton Sound (lnL = -77.3, p = 8.7e-27)
Bristol Bay (lnL = -106.1, p = 2.8e-39)
Cook Inlet (lnL = -63.06, p = 1.3e-20)
Density
Fst
B
Beaufort Sea (lnL = -268.6, p = 1.4e-87)
Chukchi Sea (lnL = -173.8, p = 2.1e-46)
Norton Sound (lnL = -192.4, p = 1.7e-54)
Bristol Bay (lnL = -181.8, p = 7.3e-50)
Cook Inlet (lnL = -68.63, p = 1)
Density
Fst

individuals recently dispersed from Cook Inlet would accentuate measured genetic differences between the source population and the splinter group, and we would thus erroneously exclude Cook Inlet.

Similar erroneous exclusions are conceivable if mating patterns differ greatly from random mating. We found no evidence of non-random mating within the Yakutat whales and a recent genetic analysis of beluga whale grouping patterns revealed that most grouping types other than cow-calf pairs are not comprised of close kin (O'Corry-Crowe et al.[6]). We conclude, therefore, that it is unlikely that colonizing groups are comprised solely of close kin or that breeding in these groups is highly skewed. So, while Cook Inlet is the likely original source of whales in Yakutat Bay, our test found that the group of whales we sampled in Yakutat is unlikely to have recently emigrated from Cook Inlet. Finally, while the new group-based assignment/exclusion method we present here has shown great promise, development is ongoing, including validation with simulated data and the exploration of other measures of genetic discreetness.

Figure 6.—The likelihood of the Yakutat group of beluga whales coming from the 5 population stocks of this species in Alaska and NW Canadian waters including Cook Inlet, using the program GELATo: A) mtDNA, and B) microsatellite loci. The null distribution of genetic distance (F_{st}-*null*) within each reference population centered on $F_{st} = 0$ (light grey bars), is compared to the observed distribution of genetic distance (F_{st}-*obs*) between the Yakutat sample set and the reference population, centered on $F_{st} \geq 0$ (dark grey bars). The distributions are generated from 1,000 re-samplings of the reference data set and associated estimation of genetic distance. The log likelihood of each F_{st}-*obs* is also reported. A high degree of overlap among the null and observed distributions indicates a high likelihood the sampled group came from that population stock.

Perspectives

This study, when viewed with growing evidence from ecological and traditional knowledge studies, established that a small breeding group of beluga whales is resident in Yakutat Bay at the warm edge of the species' range. This group has likely persisted in this region for at least several decades spanning multiple generations, and occupies a habitat unique to beluga whales in the North Pacific. Recurring immigration from Cook Inlet appears limited and dispersal to Cook Inlet from Yakutat Bay may be rare.

That these whales represent a viable functioning population is less clear. The number of breeding adults may be less than 10 individuals. While the adaptive potential of this group can influence its chances of survival in the long term, it is its small current size and the attendant demographic and genetic effects on fitness and survival that will dictate its fate in the short term.

Nevertheless, that such a small number of whales have survived on the southern edge of the species' range is encouraging. Their persistence may reflect an innate resilience of this species in marginal habitats or locations that may increase their prospects when dealing with predicted environmental and climate change. Genetic and behavioral aspects of the social nature of this species may enhance the chances of small pioneering or relict groups of beluga whales surviving on the edge of the species' range.

The management of small groupings on the species' range limit presents both unique challenges and opportunities. On the one hand, the persistence of peripheral groups may be short lived, their direct role in the maintenance or recovery of central populations over ecological timescales may be limited and their contributions to the evolutionary potential of species on evolutionary timescales may be minimal. It can be debated, therefore, whether they qualify for inclusion within Distinct Population Segments (Waples, 1991; USFWS and NMFS, 1996) under the U.S. Endangered Species Act.

On the other hand, groups, no matter how small, at the geographic limit of a species' range define the boundary of management units where the objective is to maintain all populations as functioning elements of their ecosystem, as in Population Stocks under the Marine Mammal Protection Act (Wade and Angliss, 1997). They also provide rare opportunities to investigate how species respond to environmental perturbations, including climate change, and cope with the challenges of small population size and isolation.

In the case of the belugas of Yakutat Bay, their survival thus far has likely been aided by their obscurity and the relative pristine nature of their environment. Further, the Tlingit of the Lost Coast have no tradition of hunting the whale and view the beluga as an integral part of an ecosystem that should be preserved. We recommend that further research be conducted on the population dynamics, ecology, genetics, and movement patterns of the Yakutat Bay whales. This study was a collaborative effort with the communities of this region and it is only through continued community-based research will further insight be gained and the chances of survival of this group be maximized.

Acknowledgments

Funding for this research was provided by research grants from the U.S. Marine Mammal Commission and the National Marine Fisheries Service. Biopsy sampling was conducted under NOAA permit no. 782-1719-03 issued to John Bengtson, Director, National Marine Mammal Laboratory, Seattle, Washington. The establishment of a field camp and associated activities in Disenchantment and Yakutat Bays were conducted under a Scientific Research and Collecting Permit #WRST-2005-SCI-003 from the U.S. Department of the Interior, National Park Service. We thank NOAA's NMFS Southwest Fisheries Science Center, La Jolla, California for providing lab facilities and Carolina Bonin and Amy Frey for assistance with lab work. Thanks to Rudy, Jeremiah, and Jonathon Pavlik, our field guides in Yakutat, for their assistance in so many ways. Thanks to John Jansen, Bert Adams Jr., Carolina Bonin, Eileen Henniger, Amy Frey, Aviva Nestler, Sam Williams, Ray Sensmier, and Bert Adams Sr., for their assistance in the field and to Kaja Brix and Brad Smith of the NMFS Office of Protected Resources, Alaska, and Rod Hobbs of the National Marine Mammal Laboratory for all their support. Thanks to Nelson Beaman for the Go-Random Access script. A special word of gratitude to Barbara Taylor, Phil Clapham, and Brad Smith, their comments greatly improved this paper. HBOI contribution #1973.

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Assessment of Remote Video for Monitoring Beluga Whales, *Delphinapterus leucas*, of Cook Inlet, Alaska

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Introduction

In 1979, Alaska's Cook Inlet beluga whale, *Delphinapterus leucas*, population was estimated to be 1,300 animals (Calkins[1]). Abundance surveys in the early 1990's indicated a 47% decline, and in response to this decline, NOAA's National Marine Fisheries Service (NMFS) designated the stock as depleted under the Marine Mammal Protection Act on 31 May 2000 (NOAA, 2000). On 22 October 2008 NMFS listed the Cook Inlet beluga whale as an endangered species under the Endangered Species Act (NOAA, 2008; NMFS[2]). Since then, aerial surveys have shown a continued decline to an abundance recently estimated at 312 animals (Hobbs et al., 2015). As part of the requirements of the ESA listing process, NMFS designated critical habitat for Cook Inlet beluga whales and is developing a recovery plan for the conservation and survival of this species.

One of the challenges facing managers, scientists, and others interested in the recovery and conservation of Cook Inlet beluga whales is the dearth of information about habitat use and requirements. Ongoing aerial and vessel surveys coupled with photographic identification, land-based observer efforts, and passive acoustic monitoring have provided useful insights into the Cook Inlet beluga whale occurrence and behaviors in summer months (Moore et al., 2000; Goetz et al., 2007; Funk et al.[3]; Markowitz and McGuire[4]; Markowitz et al.[5]; McGuire et al.[6,7];

[1]Calkins, D. G. 1989. Status of belukha whales in Cook Inlet. *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting, Anchorage, AK, Feb. 7–8, p. 109–112. U.S. Dep. Commer., NOAA, OCSEAP Rep., Anchorage.

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doi: dx.doi.org/10.7755/MFR.77.1.6

[2]NMFS. 2008. Conservation plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv. Reg. Off., Juneau, AK, 122 p.

ABSTRACT—Alaska's Cook Inlet beluga whales, Delphinapterus leucas, *an endangered species, were estimated by the National Marine Fisheries Service, NOAA, at a mere 312 animals in 2012. Understanding the habitat use and defining critical habitat for these whales is crucial for their conservation. The Little Susitna River Delta is thought to be an important summer foraging, mating, and calving habitat area for the species. To investigate the efficiency of new methodologies and increase our understanding of habitat use, the Alaska SeaLife Center initiated the Cook Inlet beluga whale remote monitoring pilot study in the summer of 2011 using video monitoring. Observers used two remotely controlled video cameras mounted on a 9 m tower approximately 1.5 river miles from the confluence of the Little Susitna River and the waters of Cook Inlet. Belugas were observed through the cameras from May to August 2011 as they entered the river mouth and traveled upstream past the camera site. The remotely captured behavioral information in this secluded location added finer-scale information about habitat use and behavior to the existing body of knowledge about Cook Inlet belugas. Behaviors observed and video-recorded included typical beluga behaviors (e.g., travelling, milling, and suspected feeding) along with a higher-than-anticipated occurrence of other behaviors (e.g., breaching, spyhopping, mother/newborn interactions). Additionally, detailed group composition, distribution, and duration of sighting data was collected, proving both the effectiveness and value of this monitoring method.*

[3]Funk, D. W., T. M. Markowitz, and R. J. Rodrigues (Editors). 2005. Baseline studies of beluga whale habitat use in Knik Arm, Upper Cook Inlet, Alaska: July 2004–July 2005. Rep. from LGL Alaska Res. Assoc., Inc., Anchorage, with HDR Alaska, Inc., Anchorage, for Knik Arm Bridge and Toll Authority, Anchorage, Dep. Transp. Public Facil., Anchorage, and Fed. Highway Admin., Juneau, Alaska, 232 p. (http://www.knikarmbridge.com/Tech_Reports/Boiler%20QC/Baseline%20Studies%20of%20Beluga%20Whale%20Habitat%20Use%20in%20Knik%20Arm.pdf).

[4]Markowitz, T. M., and T. L. McGuire (Editors). 2007. Temporal-spatial distribution, movements and behavior of beluga whales near the Port of Anchorage, Alaska. Rep. from LGL Alaska Res. Assoc., Inc., Anchorage, for Integrated Concepts and Res. Corp. and U.S. Dep. Transp. Marit. Admin., 73 p. http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/development/portofanc/poa2007tempspacialmovements.pdf)

[5]Markowitz, T. M., T. L. McGuire, and D. M. Savarese. 2007. Monitoring beluga whale (*Delphinapterus leucas*) distribution and movements in Turnagain Arm along the Seward Highway. Final Rep. from LGL Alaska Res. Assoc., Inc., Anchorage, for HDR and Alaska Dep. Transp. and Public Facil., 42 p.

[6]McGuire, T. L., C. C. Kaplan, and M. K. Blees. 2009. Photo-identification of beluga whales in Upper Cook Inlet, Alaska. Final Rep. Belugas re-sighted in 2008 prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for Natl. Fish Wildl. Found., Chevron Corp., and ConocoPhillips Alaska, Inc., 42 p.

[7]McGuire, T., M. Blees, and M. Bourdon. 2011. Photo-identification of beluga whales in Upper Cook Inlet, Alaska. Final Rep. Field activities and belugas resighted in 2009 prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for Natl. Fish Wildl. Found., Chevron Corp., and ConocoPhillips Alaska, Inc., 53 p. (www.cookinletbelugas.org).

Figure 1.—Alaska with a detailed map of the Little Susitna River study area and surrounding area including Upper Cook Inlet waters adjacent to the city of Anchorage. The study area is shown with distances to landmarks visible through monitoring cameras. The inset is a close up view of the river delta study area with map subdivisions from A to E. Base map source: "Little Susitna River" (lat. 61°16′22.41″ N, long. 150°15′34.32″ W, Google Earth, 15 April 2011).

McGuire and Bourdon[8,9]; Small[10]). However, these approaches are all limited in various ways (e.g., cost, opportunity, weather). None of the visual approaches provides continuity of observations at any spatial scale.

As one solution, remote video monitoring can provide a constant platform for collecting continuous occurrence (diurnal, tidal, seasonal) movement and behavior data during ice-free months from focal areas known to be important to Cook Inlet beluga whales. Remote monitoring offers the benefit of monitoring Cook Inlet beluga whales without human-caused disturbance that may result from boat-based surveys and from low-flying survey aircraft. Remote monitoring can provide longer term behavioral observations, group composition information, and has the potential for photo-identification. Remote monitoring has been used by the Alaska SeaLife Center for over a decade to monitor behavior, site fidelity, and pupping of endangered Steller sea lions, *Eumetopias jubatus*, at the Chiswell Islands (Maniscalco et al., 2002, Parker et al., 2008, Maniscalco et al., 2010) and abundance and behavior of harbor seals, *Phoca vitulina*, in Aialik Bay (Hoover-Miller et al., 2011).

Information gathered from remote video monitoring could similarly provide fine-scale details on the Cook Inlet beluga whale use of critical habitat, including diurnal, tidal, and seasonal patterns of habitat use, which scientists and managers can utilize for conservation decisions. This study tested the efficacy of remote video monitor-

[8]McGuire, T. L., and M. L. Bourdon. 2009. Predeployment visual monitoring for beluga whales in and near the Cook Inlet tidal energy project proposed deployment area, June–November 2009. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for Ocean Renewable Power Co., Anchorage, 36 p. (www.fakr.noaa.gov/protectedresources/whales/beluga/development.htm).

[9]McGuire, T. L., and M. L. Bourdon. 2011. Predeployment visual monitoring for beluga whales in and near the Cook Inlet tidal energy project proposed deployment area, May–November 2010. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for Ocean Renewable Power Co., Anchorage, 36 p. (www.fakr.noaa.gov/protectedresources/whales/beluga/development.htm).

[10]Small, R. J. 2010. Project title: Acoustic Monitoring of Beluga Whales and Noise in Cook Inlet. Final Rep. to NMFS for Grant No. NA07NMF4390364, 2 p. (www.fakr.noaa.gov/protectedresources/whales/beluga/research.htm).

Figure 2.—Tower and mounted cameras used to monitor Cook Inlet beluga whales in the Little Susitna River. Arrows indicated the location of the two cameras mounted near the top of the tower.

ing to study belugas during ice-free months in Cook Inlet.

Methods

Location

The study site was located near the mouth of the Little Susitna River, Upper Cook Inlet, Alaska. The video cameras and tower were located at (lat. 61°16′22.41″ N, long. 150°15′34.32″ W), approximately 2.4 km from the confluence of the Little Susitna River and the waters of Cook Inlet, at mean low tide (Fig. 1). This site is located in the designated critical habitat for Cook Inlet beluga whales and was selected based on results of previous Cook Inlet beluga whale studies in the area that identified it as an area of persistent beluga occurrence during the ice-free months (e.g., Hobbs et al., 2015; McGuire et al.[6,7]; McGuire and Bourdon[8,9]).

Equipment

The video camera system utilized remotely operated analog high resolution (640 x 480) camera technology made from basic Sony camera component with custom upgrades and housing (SeeMore Wildlife Systems, Homer, AK[11]). The cameras allowed an observer in an office to remotely manipulate the cameras in real-time via a microwave link. This technology has proven to be reliable for remote observations during daylight, which can approach 20 h per day in summer (Maniscalco et al., 2002; Hoover-Miller et al., 2004).

The camera system consisted of two cameras mounted to a 9 m steel tower embedded in the ground at the study site (Fig. 2). Two cameras were used to increase coverage with overlap in visual range. Only one camera feed could be utilized at a time. Each camera was equipped with a 12–18x optical and 180–300x digital zoom lenses mounted in weather proof housings and with remotely controlled pan, tilt, zoom, and windshield wiper/washer functions. Video signal was transmitted approximately 15 miles via microwave transmission. The cameras and tower were powered by a 12-volt battery system charged by solar power.

In the office, the signal was viewed and recorded in real time with typical television monitors and digital recorders. The commands for controlling the cameras were sent from custom-made software running on a desktop computer. Batteries, electronics, and the recharging system to run the cameras were located in a hard case mounted at the base of the steel tower, and the live image from the cameras was transmitted via microwave signal to a receiver. The receiver was located 15 km away on the ConocoPhillips building in Anchorage which had a line-of-sight relay for the remote acquisition of video data. The analog signal was transmitted to the receiver and required digital compression for transmission to an Anchorage-based office complete with computer, recorder, and editing equipment.

The viewing area covered by both cameras spanned from the confluence of the Little Susitna River and the waters of Cook Inlet to approximately 3 river miles upriver at mean low tide. Within the viewing area, the river width ranged from 0.1 to 0.3 miles wide.

Observing and Data Collection Protocol

Scanning Protocol

The observer monitoring effort was conducted from May to August 2011. Observations occurred during daylight hours, 5–7 days a week, with hours varied to cover different tidal stages but primarily targeting high-tide stages. Tides in this region can vary by as much as 9 m. Scans of the study area were conducted every 20 min throughout each monitoring shift (8 h). For each scan, the observer would position the camera at the farthest south or north position and slowly move the camera through the study area. Movement of the camera for observations were incremental instead of continuous, to allow for detailed observation. With each movement of the camera (~ 300 m increments), the observer paused long enough to determine if whales were present in the field of view before moving it again. Scans usually lasted between 10 and 15 min, but they were longer if belugas were present to facilitate accurate data collection.

Data Collection and Video Archiving

Data for each scan were recorded on standardized data sheets and subsequently entered into a Microsoft Office Access database. Occurrence, number, and durations of observa-

[11]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

tions of boats, harbor seals, or other river activity were recorded in the database with the beluga data. Video was recorded during the observer's shift, and video segments with belugas, boats, harbor seals, or other river activity were archived. Date and time of the footage was archived as part of the file. Video without animals or humans was discarded.

Beluga Data Collection

During real-time monitoring, when belugas were present, observers noted group location, group size, composition (i.e., color of whales and presence of dark gray calves), and behaviors. To accurately capture the dynamic movements of whales within the study area, without inflating total numbers of whales reported, a two-tiered data collection scheme was implemented. Consistent with protocols used by other beluga monitoring studies in Cook Inlet (Pinney[12]), upon sighting a group of whales for the first time the observer would keep them in view long enough to accurately assess location, composition, and behavior (tier 1, initial sighting).

After recording these data, the observer would continue to scan the study area for the presence of other groups of whales. On successive scans whales sighted were assigned a new group number and a new line of data was recorded, with the observer again documenting composition, location, and behavior, and any comments on the data sheet to indicate if this was most likely the same group as previously recorded (tier 2). Data were recorded and maintained in a database. Data entry and group coding, as well as a comparison among real-time monitoring through the systems with video recordings, are detailed in a project report (Easley-Appleyard et al.[13]).

Group location was documented using a grid system consisting of five grids (A, B, C, D, E) covering all portions of the study area visible through the camera (Fig. 1). Grid A consisted of an array of 117 500-m x 500-m cells (2.93×10^7 m^2). Grids B, C, D, and E consisted of arrays of 100m x 100m cells (144 total cells; 4.44×10^6 m^2). Each group was assigned a code and movement noted among grids to track the spatial arrangement of belugas (Fig. 1).

Behaviors

Beluga behavior was assessed for primary, secondary, and tertiary behaviors. Primary behavior was the main activity of the groups. Secondary and tertiary behaviors were less frequent activities observed sporadically in the midst of the primary activity. Primary behaviors included traveling (movement in a singular direction), milling (movement in multiple directions), and unknown. Secondary behaviors were milling, traveling, feeding suspected (bursts of speed and or localized diving), diving (arched back with brief tail fluke before submerging), spyhopping (head out of water vertically), and other. Tertiary behaviors were traveling, feeding suspected, diving, spyhopping, tail slapping, and other. Secondary or tertiary activities under the category of "other" included headstands, bobbing, listing while showing pectoral fins, and excessive splashing. Details on behaviors can be found in Easley-Appleyard et al.[13]

Nightly Reviewed Video

When conditions were acceptable, the video cameras were left on to record at the end of an observer shift and programmed to turn off at 2200 h, when diminishing daylight reduced visibility. The cameras were pointed northeast and primarily covered Grid D. Recorded video was reviewed for presence of belugas, humans, and other marine mammals, and video of any significant events was archived.

Environmental Conditions

Environmental conditions were recorded for every hour of observation during the project. Environmental data collected through visual observations included the presence (yes or no) and direction of glare within the study area, Beaufort Sea state (0 to 5), the presence of whitecaps (yes or no), percent cloud cover, and precipitation (scale of 0 to 3). The overall monitoring conditions were ranked as excellent, moderate, or poor, based on the presence of wind, whitecaps, sun glare, rain, haze, smoke, snow, and fog. Wind direction, wind speed, and air temperature were collected from the Anchorage airport station on the Weather Underground website (http://www.wunderground.com/US/AK/Anchorage.html).

Tidal Stages

Tidal stages were calculated by finding the difference between when the consecutive high and low tides occurred as reported by NOAA, Tide and Currents verified data for Anchorage (http://tidesandcurrents.noaa.gov/geo.shtml?location=99501). The number was then divided by the six tidal stages that make up a tidal cycle and times for tidal stages were calculated. Cook Inlet has 12-h tidal cycles. For the purpose of this study, the tidal stages were divided into six equal stages, averaging about two hours per stage. Being the first study of this kind on belugas, a wide variety of tidal stages were monitored. The stages used for analysis include: low ebb, low slack, low flood, high flood, high slack, and high ebb. During analysis, a tidal stage was considered covered by monitoring if there was monitoring for at least 45 min of the tidal stage.

Spatial Distribution

All grid cell locations recorded for each group sighting were tabulated at the end of each month. Total sightings for each grid cell were imported into ArcGIS ArcInfo 10.0 (ESRI, Redlands, Calif.). Cells were color coded based on the total number of group sightings

[12]Pinney, L. 2011. GIS assessment of Cook Inlet beluga whales (*Delphinapterus leucas*) habitat parameters in the Knik Arm area of Anchorage, AK. MSc thesis, Univ. Alaska Anchorage, 91 p.

[13]Easley-Appleyard, B., L. Pinney, L. Polasek, J. Prewitt, and T. McGuire. 2011. Alaska SeaLife Center Cook Inlet beluga whale remote monitoring Pilot Study. Final Rep. from Alaska SeaLife Center, Seward, 49 p. (http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/cib_susitna093011.pdf).

Table 1.—Monitoring effort in 2011 by month. Monitoring effort was defined as the time when observers conducted regular scans over the entire survey area. Because the camera was positioned in one location for nightly video, effort and results from nightly reviewed video was not included in regular monitoring effort and beluga whale presence.

Month	No. of monitoring days	Total monitoring hours (h:min)	% Month covered by monitoring effort (24/7)	Mean per day covered by monitoring effort	Mean monitoring effort h/day
May	10	42:33	18%	18%	4:15
June	30	255:06	35%	35%	8:30
July	29	222:28	30%	32%	7:40
August	24	199:24	27%	33%	7:58
Total	93	719.3			

Table 2.—Monthly observation effort and Cook Inlet beluga whale sightings by group and with calves using live-feed video monitoring from May to August 2011.

Month	No. of monitoring days	No. of days belugas observed	% Observation days belugas observed	Total monitoring hours	No. of hours belugas observed	% Monitoring hours belugas observed	No. of beluga groups observed	No. of groups with calves
May	10	2	20%	42.6	3.0	7%	11	6
June	30	11	37%	255.1	18.2	7%	16	2
July	29	5	17%	222.5	9.4	4%	8	0
August	24	20	83%	199.8	91.0	45%	34	13
Total	93	38		720.0	121.6		69	21

for that location. Specific locations for behaviors of note (suspected feeding, diving, spyhopping, breaching, bobbing, showing pectoral fins, and excessive splashing) and presence of calves (confirmed by dark color and relative size) were tabulated for the entire season, imported into ArcGIS, and color coded based on total number of sightings of each for each grid cell.

Results

Monitoring Effort

In total 720 h of monitoring, time when observers conducted regular scans over the entire survey area, were conducted over 93 days from 22 May 22 to 31 August. Throughout the project the average percentage of the day that was covered by monitoring over a 24 hour period was 32% (Table 1). Night video was not included in regular monitoring effort because cameras were positioned in one location overnight.

Equipment Function

Over the entire project period, image quality and clarity was lower than anticipated, which prevented the identification of individual beluga whales. On several occasions (<10) the cameras lost connection, lost movement, or provided significant static to prevent data collection. In most cases camera function was fully restored within the hour by restarting the system, but on more than one instance connection was lost for more than 12 h. These complications resulted in lost video footage for several days each month.

Image resolution was lower than anticipated for the project due to degradation of signal transmission within the office building. Installation of high frequency signal transmission cables was not possible in the office space used. Therefore the signal had to be compressed and image resolution was reduced to 300 x 225 pixels.

Beluga Observations

Belugas were observed on 38 of the 93 days during the May–Aug. study period. In total, 69 groups of beluga whales were observed within the study area. Belugas were seen most often in August, with belugas seen on 83% of observations days, and least often in July, with sightings on only 17% of observation days (Table 2). Calves were observed in 30% of the groups, and the greatest number of groups with calves (13 groups) was observed during August (Table 2). Groups ranged in size from 1 to 59 whales. Time that groups remained in the study area ranged from 1 to 498 min (8.3 h; Table 3). More than half of groups observed (52%) remained in the study area for less than one hour.

Spatial Distribution

Beluga whales were observed throughout the study area in all study grids. A majority of groups (39 of 69 or 57%) were observed either spread across or traveling through multiple study grids. Grids C and D were closest to the camera and therefore provided the greatest detail within beluga groups. Sighting rates were highest in grid D and lowest in grid E (Fig. 3). Groups containing calves were seen more often in grids C and D, 14 and 16 groups, respectively, than they were elsewhere in the study area (Fig. 4).

Tidal and Temporal Beluga Presence

Although belugas were seen during all tidal stages, after standardizing for unequal monitoring effort, during daylight hours belugas were seen most

Table 3.—Monthly summary of beluga whales per group sighting data 22 May–31 Aug. 2011. Activity codes: 0=Unknown, 1=Traveling/moving, 2=Diving, 3=Mating, 4=Spyhopping, 5=Breaching, 6=Feeding observed, 7=Feeding suspected, 8=Milling, 9=Startled effect, 10=Tail slapping, 11=Avoiding predation, 12=Calving, 13=Abrupt dive, 14=Disperse, 99=Other.

Month	Max. sighting duration/ group (min)[1]	Locations by grid	Max. group size	Max. no. calves/ group	1° Activity	2° Activity	3° Activity
May	33	A,B,D,E	30	6	1,8	1,2	-
June	344	A,B,C,D,E	46	3	0,1,8	1,2,7,8	1,2
July	158	B,C,D	14	0	1,8	1,7,8	7
August	498	A,B,C,D,E	59	3	0,1,8,99	1,2,4,7,8,99	1,2,4,7,10,99

[1]Maximum sighting duration is the maximum length of time belugas were seen continuously and may include more than one group.

Table 4.—Tidal stages with monitoring effort and beluga presence, using live-feed video monitoring, from 22 May–31 Aug. 2011.

Tide	No. of tide stages covered by monitoring effort[1]	No. of tidal stages with beluga presence	Beluga presence relative to monitoring effort
Low ebb	55	11	20%
Low slack	38	3	8%
Low flood	50	9	18%
High flood	85	21	25%
High slack	94	32	34%
High ebb	73	20	27%

[1]Tidal stages per tidal type, 2011, 24 h/day (22 May 2011–31 Aug. 2011). Tidal stage was considered covered by monitoring if there was monitoring of at least 45 min of the tidal stage.

often during high tides and less frequently during low tide stages. Within tidal stages, belugas were more often seen in high slack tide (i.e., peak water levels; 32 out of 96 sightings) and least often during low slack tide (i.e., lowest water levels; 3 out of 96 sightings; Table 4). Belugas were seen throughout daylight hours in which monitoring occurred (0645 h to 2024 h). Nightly video, in a following section, indicated that belugas were present up the river during all but low ebb tides.

Behavior

In all months, May through August, primary behaviors included traveling and milling (36% and 59% of total primary behaviors, respectively). In June and August some behaviors were noted as unidentifiable due to poor visibility (Table 3). Secondary behaviors included traveling (28% of total secondary behaviors) and diving (17%) in all months, except no diving was recorded in July. Secondary behaviors also included suspected feeding (34%) and milling (20%) (June–Aug.), as well as spyhopping, tail stands, and some unknown behaviors (2%) (Aug.). Additionally, extended adult/calf interactions were observed, but this was not part of our directed behavioral observations and is therefore ancillary. Suspected feeding and diving behaviors were seen most frequently in grids C and D (Fig. 5, 6). Spyhopping was observed in grids B, C, and D. Tail slapping was recorded once in grid C. Headstands occurred in grids B, C, and D. Bobbing and showing pectoral fins occurred in grid C. Vigorous splashing occurred in grid B.

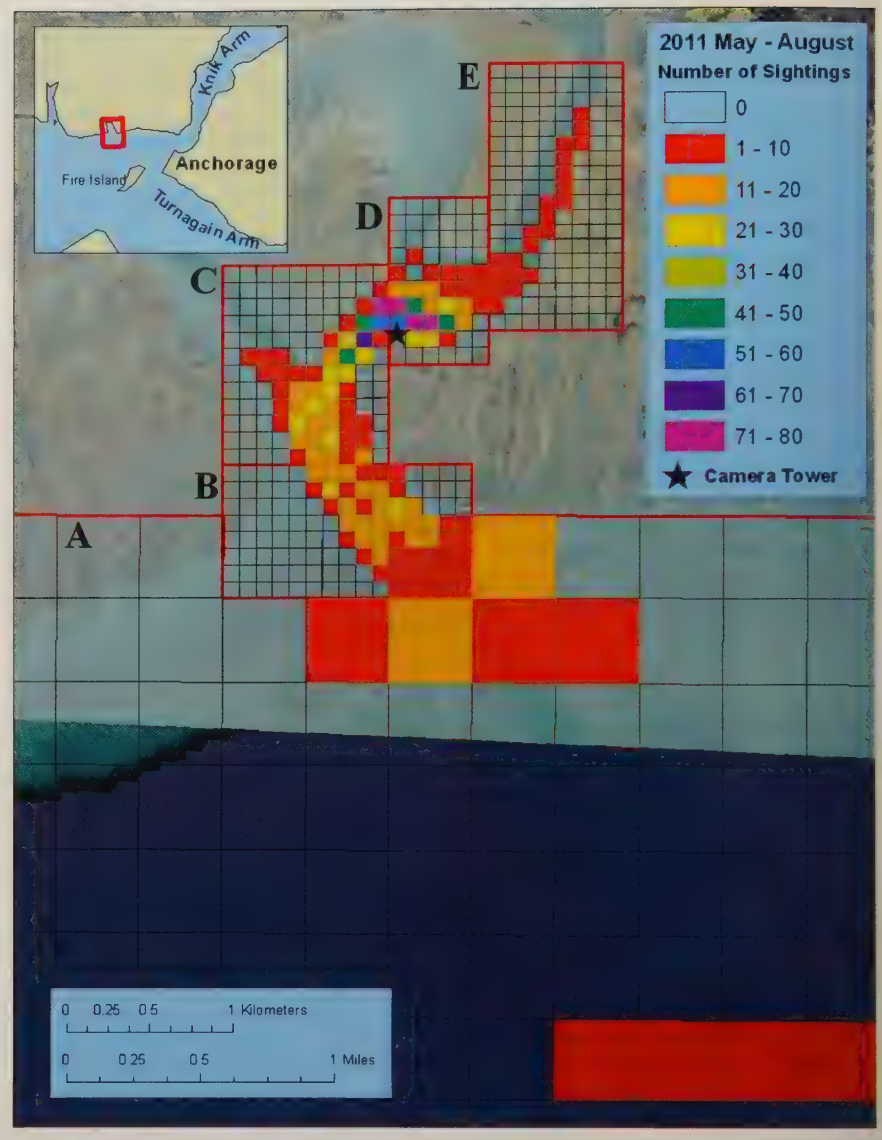

Figure 3.—Spatial distribution of sightings of beluga whale archival groups in May–Aug. 2011 with an inset of the relative position of the study area within Upper Cook Inlet. A sighting is defined as the presence of beluga whales during the duration of a single scan. Highlighted grid cells represent locations where beluga whale groups were observed. Color scale indicates total number of group sightings in each grid cell during 2011. Beluga whales were observed in grids A, B, C, D, and E. Group sighting rates were highest in grids C and D.

Other Marine Mammals

Harbor seals, *Phoca vitulina richardsi,* were observed on 91 of the 93 days of monitoring. An average of 10 harbor seals were observed during a scan. The largest group of harbor seals recorded in a scan was 42, with 40 seals hauled out at the mouth of the river and two seals in the water near belugas. Harbor seals were observed with fish in their mouths 18 times on 15 days during the study. Harbor seals were observed within

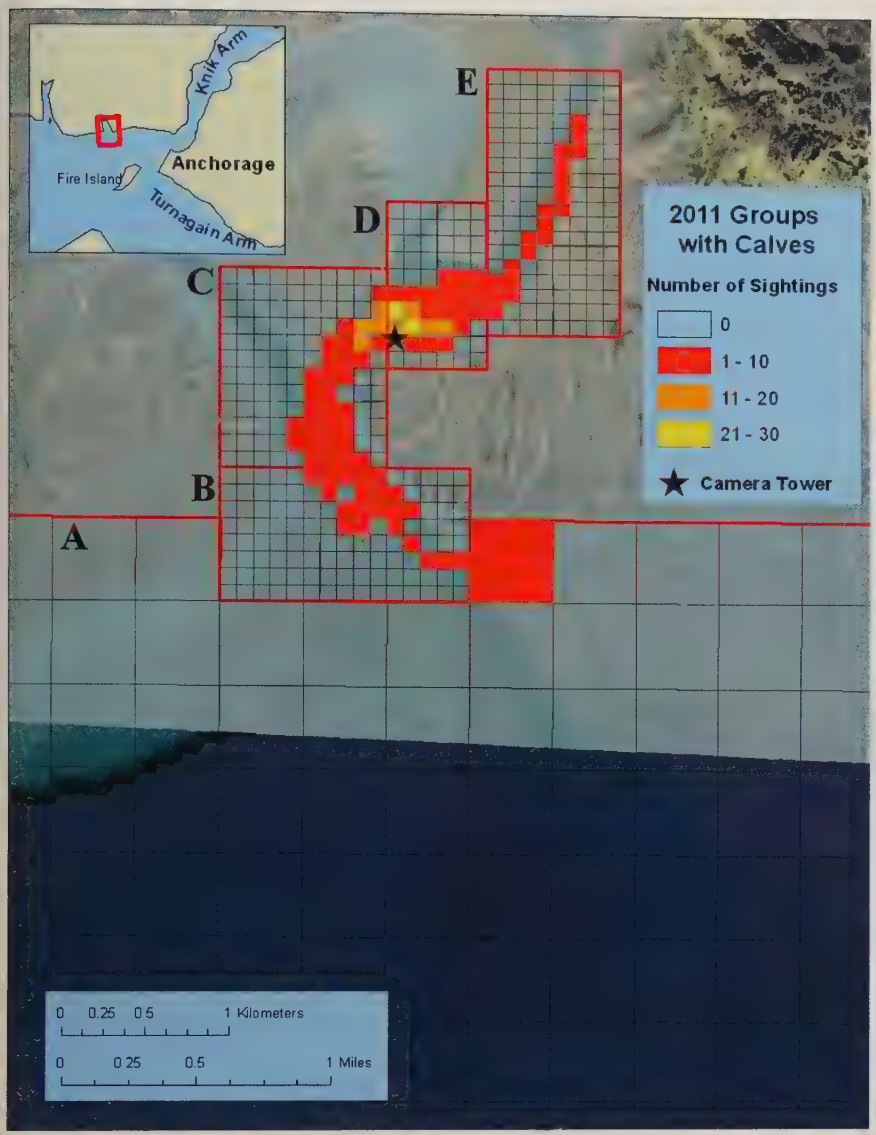

Figure 4.—Spatial distribution of sightings of beluga whale groups with calves in May–Aug. 2011 with an inset of the relative position of the study area within Upper Cook Inlet. A sighting is defined as the presence of beluga whales during the duration of a single scan. Highlighted grid cells represent locations where beluga whale groups with calves were observed. Color scale indicates total number of sightings in each grid cell during 2011.

100 m, and as close as 1 m, of belugas during 49 of the scans and on 20 of the monitoring days. Other marine mammals known to inhabit Cook Inlet, such as killer whales, *Orcinus orca;* Steller sea lions, harbor porpoise, *Phocoena phoconea;* and Dall's porpoise, *Phocoenoides dalli,* were not observed.

Environmental and Equipment Conditions

Environmental conditions that hindered monitoring effort included: high winds, low tide, and glare (reflection of sunlight off of the water). High winds caused the camera to shake, which resulted in poor and sometimes obstructed visibility. Monitoring conditions often deteriorated during low tide due to low water levels and higher possibility of reflection off the surface of the water. There were also instances when glare was not present, but low or poor light levels along the water decreased visibility. Environmental conditions during the scans were noted and did not necessarily hinder monitoring of the entire study area.

Human Activity

Thirty-five independent sightings of vessels were observed in the Little Susitna River during May through August monitoring efforts. Vessel sightings ranged from small boats to skiffs and jet skis, and in numbers from one to three at a time. Most of the vessels were traveling through the study area and did not remain in view for more than a few minutes. In most cases, but not all, vessel operators slowed down when whales were present.

Nightly Reviewed Video

A total of 67.5 h of video recorded over 13 nights was reviewed for presence of belugas, humans, and other marine mammals. On 5 of the 13 nights belugas were seen in the video viewing area. On all five nights that belugas were observed during nightly reviewed video, belugas were also observed during high tide earlier in the day during scheduled monitoring efforts. Belugas were observed during all tidal stages except low ebb; however low ebb only occurred twice in the nightly reviewed video. During nightly sightings belugas were seen milling the majority of the time; however, diving, breaching, and a tail slap were also recorded. Vessel traffic was observed on five of the nights, and vessels traveled both up and down stream. Harbor seals were viewed swimming in the area on nine of the nights, with one record of a harbor seal swimming near belugas.

Discussion

We were able to document the occurrence, relative abundance, and surface behavior of beluga whales near

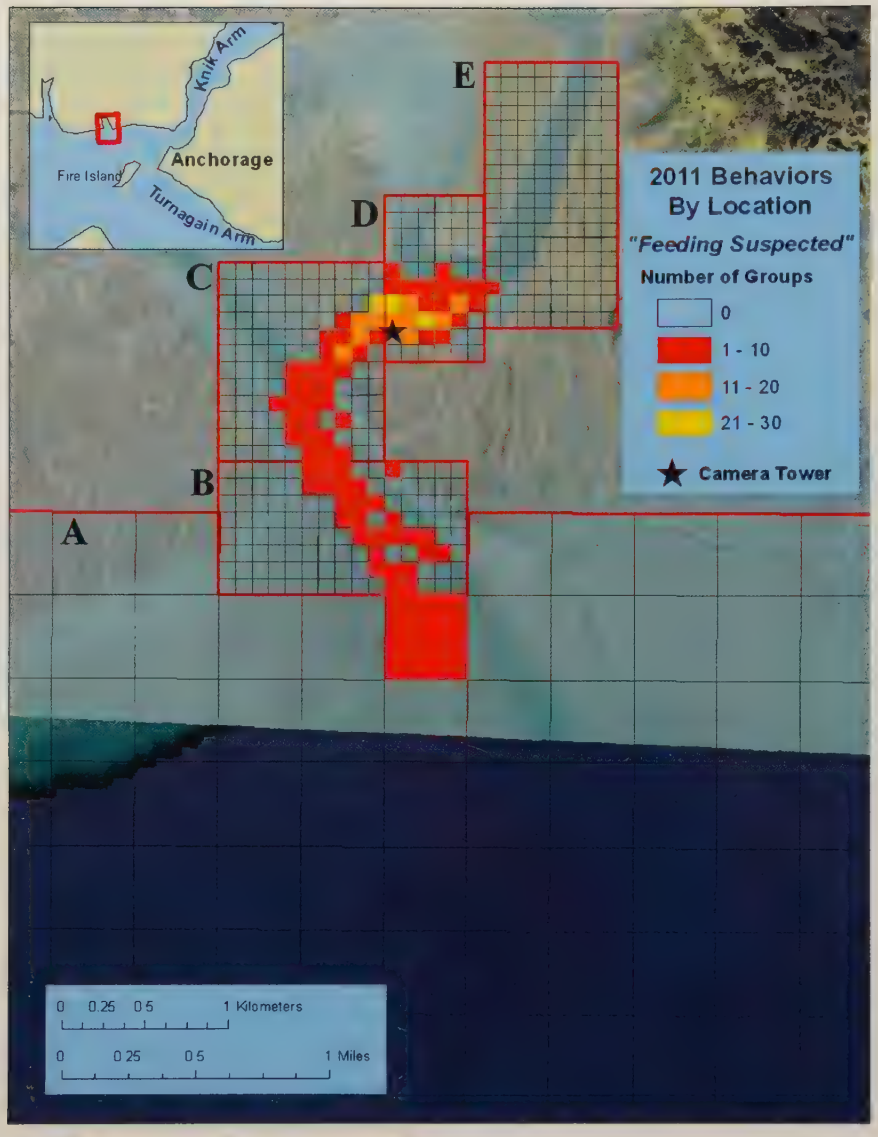

Figure 5.—Spatial distribution of sightings of beluga whale groups engaged in suspected feeding behavior in May–Aug. 2011 with an inset of the relative position of the study area within Upper Cook Inlet. Highlighted grid cells represent locations where beluga whale groups were observed engaged in suspected feeding behavior. Color scale indicates total number of sightings in each grid cell during 2011. Beluga whales were observed engaged in suspected feeding behavior in grids A, B, C, D, and E. Suspected feeding behavior was observed most often in grids C and D.

the mouth of the Little Susitna River during the ice-free months of 2011.

Beluga Observations

Spatial Distribution of Beluga Whales

Groups were seen through all grid areas; however belugas were seen most often and in the greatest detail and numbers in grids C and D. Calves were more often identified in grids C and D as well, most likely because grids C and D were closest to the camera and therefore provided the greatest detail within beluga groups. However, the ability to see beluga whales was not equal in the different grids due to distance from camera and environmental conditions. Sighting rates were lowest in grids A and B due to distance from the camera and visibility in grid A of the study area was often poorer than other grids, making comparisons between grids problematic

Beluga groups were observed to spend longer periods of time near shore than in mid-river. For example, belugas were seen near shore in grids C and D, which are situated in a bend of the river. The hydrodynamics of this location may have caused fish to become disoriented and/or concentrated, making them easier for belugas to capture compared to other locations in the study area.

The greatest numbers of calves were observed in grids C and D; however these grids were also the areas closest to the camera. Calves may have been underrepresented in grids A, B, and E, because of calf coloring (gray calves blend in with the turbid gray water of Upper Cook Inlet), greater sighting distance, and the resulting diminished image quality.

Tidal and Temporal Beluga Presence

With this project in its pilot year, observer monitoring shifts were scheduled around high tide, in anticipation that river levels during other tidal stages would be too low to allow belugas to safely navigate the relatively shallow river. During high tides belugas have been seen to move into narrower channels in the inlet, departing during ebb tides (Moore et al., 2000; Ezer et al., 2008). Belugas were seen most often and in the largest groups during peak water levels (even after standardizing for the greater monitoring effort made during this tidal stage), but belugas were observed in the river during low tidal stages as well.

The occurrence and number of beluga whales increased drastically in August, as did the number of groups containing calves and the observance of rare behaviors. Beluga sightings in August occurred almost every day of monitoring effort and for longer durations than sightings in May, June, and

July. Calf sightings are likely to have increased, since all animals would have calved by of the end of August; calves are larger and coloring is more detectable with age. These factors all facilitate higher detections rates for calves. We speculate higher adult counts may be due to greater fish presence in the river. The river may also provide calmer and narrower waters for calf care.

Beluga Behavior

One aspect of behavior that is important to managers when evaluating the value of habitat to beluga whales is feeding behavior. Although actual feeding could not be observed in the turbid waters, behaviors that were suspected to be feeding were documented. Suspected feeding was documented if behaviors were indicative of chasing prey with burst speeds, lunges and/or diving in a focused location. Often these behaviors were observed in proximity to seals surfacing or foraging with fish in their mouth.

These behaviors of interest were most often seen in grids C and D, which may indicate these areas are preferred feeding habitats within the study area. The observations of these behaviors that were recorded as part of this study could be due in part to the sheltered, low-disturbance, and abundant forage fish qualities of the Little Susitna Delta. Nearshore travel and slower transit time is suggestive of foraging behavior and has been shown in higher frequency in the Little Susitna and Susitna river areas (Goetz et al.[14]) However, these areas were also the closest to the camera and thus may have afforded a better view. This method did provide finer detailed information to the existing body of knowledge about this species by allowing focused long term observations with no disturbance to the animals.

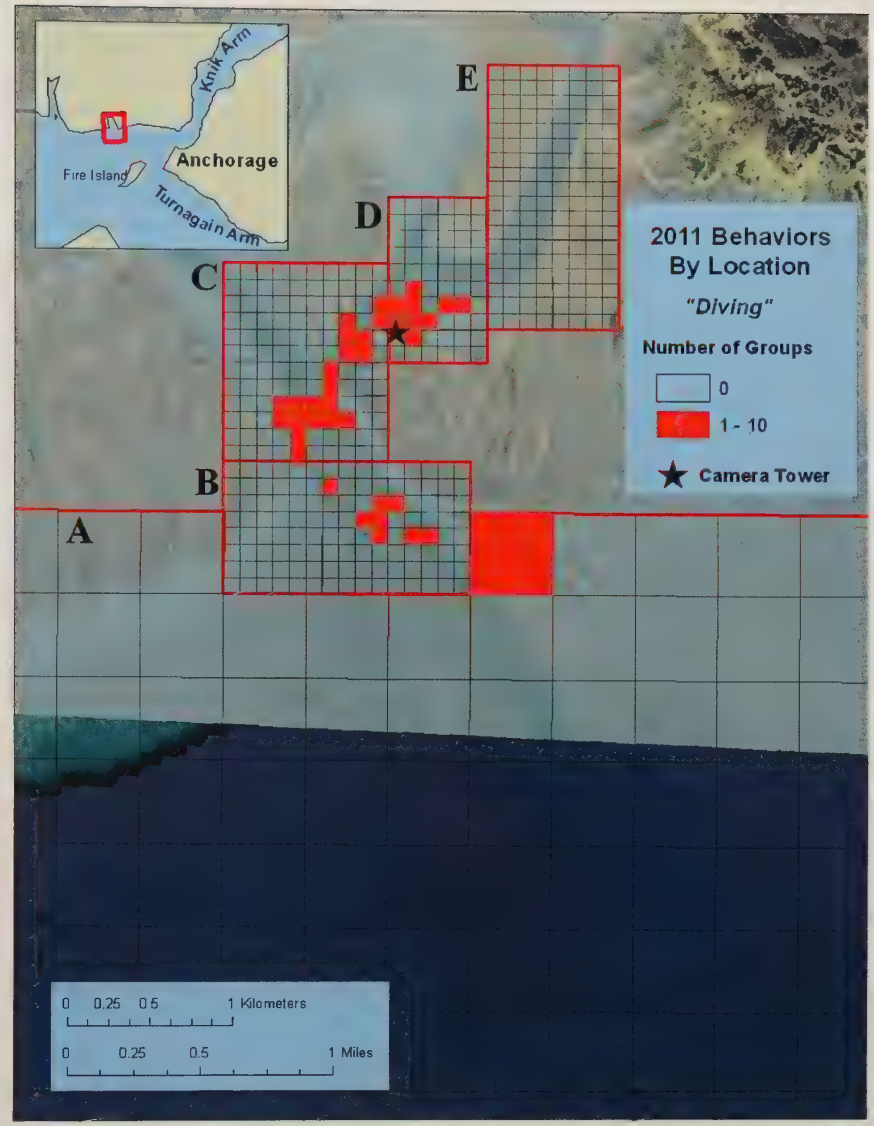

Figure 6.—Spatial distribution of sightings of beluga whale groups engaged in diving behavior in May–Aug. 2011 with an inset of the relative position of the study area within Upper Cook Inlet. Highlighted grid cells represent locations where beluga whale groups were observed engaged in diving behavior. Color scale indicates total number of sightings in each grid cell during 2011. Beluga whales were observed engaged in diving behavior in grids A, B, C, and D.

Behaviors seldom observed during other beluga whale studies, such as breaching and spyhopping, in the Cook Inlet population were documented during this study. These behaviors were on the nightly reviewed video on two separate days. The behaviors only occurred in grids C and D. Again, this could be due to better visibility and closer proximity to the camera. It could also be because the behaviors were seen up the river, away from the mouth, near the camera site, which was sheltered and had fewer disturbances in comparison to the river mouth. Other studies within Cook Inlet also note spyhops as uncommon occurrences and do not note breaches (Markowitz and McGuire[4];

[14]Goetz, K. T., P. W. Robinson, R. C. Hobbs, K. L. Laidre, L. A. Huckstadt, and K. E. W. Shelden. 2012. Movement and dive behavior of beluga whales in Cook Inlet, Alaska. AFSC Processed Rep. 2012-03, 40 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle WA 98115 (http://www.afsc.noaa.gov/Publications/ProcRpt/PR2012-03.pdf).

Goetz et al.[14]; Cornick and Kendall[15]; USAG-Alaska[16]), nor do studies outside Cook Inlet, although their primary focus was diving behavior (Martin et al., 1998; Kingsley et al., 2001; Martin et al., 2001).

Reviewed Video

One added advantage of this project is the ability to review recorded video. Real-time beluga whale data collection presents a time-restricted atmosphere as observers document accurate numbers, behaviors, and group composition before whales disappear from view. Collecting data from video of previously recorded beluga groups allowed observers to review events as many times as necessary and on slow playback to achieve highly accurate documentation.

Many interesting beluga whale behaviors happen in a flash and are therefore likely to be missed by observers in real time. The ability to pause video when taking notes increases the likelihood of catching these elusive events. For example, a tail slap and a startled response were documented in recorded video from May and June, although these behaviors were not captured in real-time data from the same time period.

When in the field and monitoring in real-time it is often difficult to recall exactly when a beluga sighting ends. Frequently observers find themselves waiting a few minutes or more to be sure that a sighting was actually the last observation of a particular group. Because of the ability to rewind video, resulting sighting times and durations are thought to be more precise. One caveat, however, is that an observer collecting data from previously recorded video would have no way of knowing if whales were present before or after video clips unless noted.

Picture quality was lower than anticipated and therefore recorded images from only one individual beluga whale were of sufficiently high image quality to allow for positive identification through LGL's Cook Inlet beluga photo-identification project (McGuire et al.[7]). With increased image quality, photo-id of belugas would be more feasible. The full project report (Easley-Appleyard et al.[13]) provides a more detailed review of live video feed versus recorded video footage.

Nightly Reviewed Video

Although the entire study area was not captured in nightly video, night recordings provided valuable information about beluga presence outside of standard monitoring efforts. Nightly video revealed that belugas travel within the study area during both high tides of the day. Although nightly video was captured during other tidal stages, no overnight activity was observed except during high tide. Behaviors not seen during daytime monitoring efforts (e.g., breaching) were captured during nightly video. Vessel traffic was also noted, and nighttime monitoring was helpful in determining if there were changes in vessel traffic during times when observers were not on shift.

Other Marine Mammals

This study was as useful for monitoring harbor seals as it was for monitoring belugas. Harbor seals were often seen feeding on fish, presumed to be Pacific salmon, *Oncorhynchus* spp., based on the size and shape of the fish, within 1 m of belugas. The harbor seal and its confirmed prey could be used as a proxy for suspected feeding behavior of beluga whales. Density of harbor seals coincided with density of belugas during the months of monitoring.

Human Activity

This study was useful for monitoring the interaction between human activities and belugas. On the occasions when vessels and beluga whales were present, vessel operators usually slowed or stopped; however, on two occasions vessels failed to slow or yield when belugas were in close proximity. It is possible that operators were unaware of the presence of whales at these times. Monitoring vessel activity in critical areas can help guide decisions on how to best educate boaters about endangered wildlife.

Project Challenges

As with any method of marine mammal monitoring and data collection, there were advantages and disadvantages to this method, and they became apparent over the course of the season.

One disadvantage of remotely-operated video camera systems is the lack of peripheral vision. The field of view available through the human eye is much wider than through the camera lens. On-site observers are able to survey more of any study site without losing sight of whales in view. The limited view through the camera forces observers to move the camera away from groups of whales periodically to ensure that no other groups are present within the study site.

A second challenge was that smaller darker animals may have been underestimated at the edge of the camera boundaries. This is most likely due to low contrast between the water color and calf color. This was increasingly challenging in the more distant grids. The addition of a second camera with a wider field of view with higher resolution that can be run concurrently with the camera focused on the whales would potentially address these issues.

Lastly, as previously mentioned, resolution was lower than anticipated which limited animal identification. Increased camera resolution or installation of high frequency signal transmission cables at the receiver site may help improve signal reception.

Conclusions and Recommendations

Several unique benefits from video monitoring became apparent through the course of the season. Observers actively manipulating the cameras were able to capture extreme close-ups of

[15]Cornick, L. A., and L. Saxon Kendall. 2008. Distribution, habitat use, and behavior of Cook Inlet beluga whales in Knik Arm, fall 2007. Rep. prep. for Integrated Concepts and Research Corporation, Port of Anchorage, and U.S. Dep. Transp. Marit. Admin., Alaska Pacific Univ., Anchorage, 29 p. (https://www.alaskafisheries.noaa.gov/protectedresources/whales/beluga/development/portofanc/poa2007habitatknikarm.pdf).

[16]USAG-Alaska. 2010. Beluga observational studies on Eagle River Flats, Fort Richardson, Alaska 2009. Fort Richardson, Alaska,

individual whales, including newborn calves, and rare behaviors with absolutely no physical disturbance to these animals. One of the most rewarding and valuable aspects of this project has been video recording of behaviors rarely seen by observers in the field, such as breaching, spyhopping, and extended video of adult and newborn calf interactions. Many of these observations were captured when cameras were left on overnight. This was also beneficial for determining beluga presence while observers were not on shift.

Although the greatest number and highest frequency of belugas were seen duing high tidal stages, belugas were also seen in the river during low tides as well. Unless future research study objectives are framed around high tide, future monitoring efforts would be best if they were evenly distributed across all tidal stages so the river in low tidal stages is not under documented. The addition of a second camera with a wider field of view and higher resolution would also be recommended for future work.

The ability to review archived video for data collection and validation purposes resulted in a more accurate dataset than could be captured in real-time. In the future and with improved image quality, archived video could be used to train future observers, educate the public, and for a wealth of potential research questions. Remote observations allow for a more-comfortable work environment for observers, which may reduce observer fatigue, compared to observers stationed at the field site. Field safety protocols are not necessary with remote monitoring. Combined, these factors allow a single observer to monitor for up to 8 h without excessive fatigue or threats to physical safety. Aside from the initial camera installation at the site, there is no travel time or cost associated with remote monitoring which would be incurred by observers operating in remote locations.

Because of the nature of beluga whales and the endangered status of the Cook Inlet population, an increased effort toward educating boaters about wildlife awareness would be beneficial. Monitoring vessel activity in critical areas can help guide decisions on how to best educate boaters about endangered wildlife. On a broader scale, compiling a comprehensive habitat-use assessment of Cook Inlet is difficult in general, and impossible for any single monitoring program or research method. Land-based visual observations, aerial surveys, satellite tagging, acoustic surveys, and photo-identification studies are all adding valuable pieces of information to this effort.

Through this pilot study, remote video monitoring has demonstrated its value as a method to provide habitat use data on Cook Inlet beluga whales. Information provided by remote video monitoring in the 2011 field season includes spatial and temporal distribution patterns of belugas in the Little Susitna River during ice-free months. This type of observation method, could add finer detailed information to the existing body of knowledge about this species including potential nursery and foraging habitat use. The use of remote video monitoring in other areas in upper Cook Inlet with similar physical qualities could be very beneficial to a more comprehensive understanding of the relationship between Cook Inlet belugas and their habitat.

Acknowledgments

This research project would not have been possible without the support of many others. We would like to acknowledge and extend our gratitude for the following people and companies that have made this project a success: Ian Dutton, Rasmuson Foundation, for the project concept; ConocoPhillips, with special thanks to Caryn Rea, for office space, technical support, parking, and encouragement; Discovery Drilling, Anchorage, for tower design and installation; U.S. Department of Defense for scientific expertise on camera location and project focus; and the National Marine Fisheries Service for funding the project.

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NOAA. 2000. Designating the Cook Inlet, Alaska, stock of beluga whale as depleted under the Marine Mammal Protection Act (MMPA). 65 Fed. Regist. 34590 (31 May 2000), p. 34,590–34,597 (avail. online at: https://federalregister.gov/a/00-13371).

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Diet of Beluga Whales, *Delphinapterus leucas*, in Alaska from Stomach Contents, March–November

LORI T. QUAKENBUSH, ROBERT S. SUYDAM, ANNA L. BRYAN, LLOYD F. LOWRY, KATHRYN J. FROST, and BARBARA A. MAHONEY

Introduction

At least five stocks of beluga whales, *Delphinapterus leucas*, occur in the waters of Alaska (Fig. 1). These stocks were tentatively identified by their summer distributions (Frost and Lowry, 1990; Richard et al., 2001), and were later confirmed genetically (O'Corry-Crowe et al., 1997, 2002, 2010). The distribution of beluga whales in Alaska is discontinuous from Yakutat Bay[1, 2] to Cook Inlet to Bristol Bay. The entire area from Bristol Bay northward and eastward to Canada is used by belugas; the Bering and Chukchi seas are used year-round and the Beaufort Sea is used in summer (Frost and Lowry, 1990).

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doi: dx.doi.org/10.7755/MFR.77.1.7

[1]There is a small group of <20 belugas that appear to be resident in Yakutat Bay, a deepwater fiord (Laidre et al., 2000; Allen and Angliss, 2011)

[2]O'Corry-Crowe, G., W. Lucey, C. Bonin, E. Henniger, and R. Hobbs. 2006. The ecology, status and stock identify of beluga whales, *Delphinapterus leucas*, in Yakutat Bay, Alaska. Rep. to U.S. Mar. Mamm. Comm., NMFS-YSB-YTT, 22 p.

ABSTRACT— At least five stocks of beluga whales, Delphinapterus leucas, *are found in Alaska waters: Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet. The two northernmost stocks (Beaufort Sea and eastern Chukchi Sea) are highly migratory; the two southernmost stocks (Bristol Bay and Cook Inlet) are nonmigratory. Little is known about the seasonal movements and distribution of the eastern Bering Sea stock. Beluga populations in Alaska are thought to be stable or increasing, except for the Cook Inlet stock which is listed as endangered under the Endangered Species Act.*

We analyzed stomach contents from beluga whales collected between the months of March and November taken in subsistence harvests, from belugas found dead, and from belugas collected for research. We describe prey species and their percent frequency of occurrence (% FO) as well as potential biases from the seasonality of prey relative to the timing of sampling, and differential feeding and digestion. Diet was highly variable among stocks. The predominant fish species of the Beaufort Sea stock was Arctic cod, Boreogadus saida *(21% FO), although shrimp (60% FO) and smoothskin octopus,* Benthoctopus leioderma *(42% FO) were found more frequently. Although the eastern Chukchi Sea stock ate more saffron cod,* Eleginus gracilis *(7% FO) than Arctic cod (3% FO), shrimp (73% FO) and echiurids (27% FO) were more prevalent than fish. The eastern Bering Sea stock had the most diverse diet, and dominant fish species included saffron cod (95% FO), rainbow smelt,* Osmerus mordax *(62% FO), several species of sculpin (Family Cottidae) and flatfish (Family Pleuronectidae), both at 48% FO, and Arctic cod at 43%. Dominant invertebrates included shrimp (86% FO), with polychaetes, isopods, bivalves, amphipods, and echiurids ranging from 29 to 38% FO. Pacific salmon,* Onchorhyncus *spp., predominated over cod in Bristol Bay (81% FO) and Cook Inlet (67% FO) beluga stocks, and invertebrates appeared to be less prevalent prey. In Bristol Bay, smelt were also eaten more often (43% FO) than cod (3% FO), while in Cook Inlet cod were eaten more often (39% FO) than smelt (11% FO). Invertebrates were common in the diet of all Alaska beluga stocks and shrimp (mostly from the family Crangonidae) were the most prevalent.*

Beluga whales in Alaska appear to follow one of two life history strategies: migratory and nonmigratory. Migratory stocks use shallow nearshore and deepwater offshore habitats (Hazard, 1988; Frost and Lowry, 1990), and include the eastern Chukchi Sea stock (population size ~4,000 (Allen and Angliss, 2011)) and the Beaufort Sea or Mackenzie stock (population size ~39,000 (Harwood et al., 1996; Allen and Angliss, 2011)).

Nonmigratory stocks use shallow, estuarine habitats year-round and include the Bristol Bay and Cook Inlet stocks. The Bristol Bay population is increasing (Lowry et al., 2008) and is estimated to be ~3,000 (Allen and Angliss, 2011). Local sightings and satellite telemetry confirm that belugas occur in Bristol Bay in all months of the year (Harrison and Hall, 1978; Frost and Lowry, 1990; Lensink[3]; Quakenbush and Citta[4]; Quakenbush[5]).

The population in Cook Inlet is estimated to be 312 whales and appears to be decreasing at 1.6% per year (Hobbs et al., 2015). The population declined dramatically between 1994 and 1998 (Hobbs et al., 2000) and the stock was determined to be depleted under the Marine Mammal Protection Act in 2000 (NOAA, 2000); the original cause of the decline is believed to be overharvest. Between 1999 and 2006 the harvest was restricted to five

[3]Lensink, C. J. 1961. Status report: beluga studies. Alaska Dep. Fish Game, Juneau. Unpubl. rep., 38 p.

[4]Quakenbush, L., and J. Citta. 2006. Fall movements of beluga whales captured in the Nushagak River in September 2006. Unpubl. rep. to Alaska Beluga Whale Committee, P.O. Box 69, Barrow Alaska 99723, 9 p.

[5]Quakenbush, L., Alaska Dep. Fish Game, 1300 College Road, Fairbanks. Unpubl. data.

belugas, and after 2006 no harvest has been allowed.

In October 2008, the Cook Inlet beluga whale population was listed as endangered under the Endangered Species Act (NOAA, 2008). Aerial surveys (1994–2011) and satellite telemetry (1999–2002) have shown that Cook Inlet beluga whales remain in the Cook Inlet area all year (Rugh et al., 2000, Hobbs et al., 2005). Except for Cook Inlet belugas, the other four beluga stocks in Alaska continue to be harvested for subsistence by coastal indigenous people and harvests are sustainable (Allen and Angliss, 2011). The Beaufort Sea stock is also harvested in Canada during summer; most of the Alaska harvest of this stock occurs during the spring migration.

The eastern Bering Sea beluga stock is found in the Yukon-Kuskokwim Delta area and in Norton Sound in summer. Aerial surveys conducted there provide a population estimate of ~18,000 (Allen and Angliss, 2011). The winter range of the eastern Bering Sea stock is unknown; therefore it is not known whether this stock is migratory.

Throughout their range, belugas feed on a variety of fish and invertebrates, often on prey that form concentrations such as schooling fish and shrimp (Seaman et al., 1982). Beluga whale diet has been described in Canada (Doan and Douglas, 1953; Sergeant, 1973; Vladykov[6]), Russia (Kleinenberg et al., 1964; Tomlin, 1967), and Svalbard and northwestern Europe (Lono and Oynes, 1961). In Alaska, information on beluga whale diet is limited to one published paper by Seaman et al. (1982) describing stomach contents from 119 beluga whales from six locations in the Bering and Chukchi seas but none from Cook Inlet. Additional Bristol Bay diet information was recorded in unpublished Alaska Department of Fish and Game (ADFG) reports (Brooks[7, 8]; Lensink[3]; Klinkhart[9]; Vania[10]) and by Frost et al. (1984).

Information collected since Seaman et al. (1982) from Kotzebue Sound is provided in an unpublished report by Lowry et al.[11] Based on traditional ecological knowledge, Huntington et al. (1999) described the diet of belugas in the nearshore areas of the eastern Bering Sea, Kotzebue Sound, and the eastern Chukchi Sea to include a variety of prey items, but primarily fish. Cook Inlet beluga prey have been indirectly described by relating whale movements to seasonal fish runs in a publication on traditional ecological knowledge from the beluga hunters of Cook Inlet (Huntington, 2000) and in published and unpublished reports (Fall et al., 1984; Hobbs et al.[12]).

This paper provides: 1) an updated description of the diet of beluga whales in Alaska using identifiable prey items found in their stomachs between 1954 and 2012, and 2) a comprehensive description of diet from stomach contents of Cook Inlet beluga whales.

Methods

Data included in this study came from the stomachs of beluga whales: 1) harvested for subsistence, 2) found dead, and 3) collected for published (Frost et al., 1984) and unpublished ADFG diet studies (Brooks[7, 8]; Lensink[3]; Vania[10]; Lowry et al.[11]; and ADFG[13]). We assigned each beluga to a stock based on collection timing and location (Fig. 1). Collections were made between March and November.

Stomachs and stomach contents were handled in several ways: 1) stomachs were collected whole and frozen, 2) stomach contents were removed and frozen, or 3) stomach contents were removed and placed in 10% formalin. In the laboratory, contents were weighed to the nearest 0.1 g and then rinsed with fresh water on a 1.0 mm sieve stacked on a 0.5 mm sieve. For frozen whole stomachs, all parts of the stomach were opened and rinsed over sieves so that all otoliths, fish bones, and cephalopod beaks that tend to adhere to the stomach lining were collected. In some cases, incomplete stomachs or a subsample of contents were collected, and in other cases prey items were identified visually in the field without collecting the stomach; these were noted by individual beluga in the database. Prey items were sorted into major taxonomic groups and identified to the lowest taxonomic level.

Fish were tabulated by counting whole fish when present and by adding the maximum count of left or right otoliths plus half of the count of otoliths that could not be identified as left or right. Lengths of otoliths that did not appear degraded were measured to the nearest 0.1 mm. Otolith lengths were converted to fish lengths using conversion equations (e.g., Frost and Lowry, 1981; Seaman et al., 1982; Harvey et al., 2000) when possible. Converted lengths are considered minimum lengths because erosion of the otoliths caused by digestion is expected to decrease otolith length and because some equations are known to have poor correlations (Harvey et al., 2000).

Cephalopods were identified by their beaks (Clarke, 1986). We used the maximum count of upper or lower beaks to determine the number consumed. The lower beak hood lengths

[6]Vladykov, V. D. 1946. Etudes sur les mammiferes aquatiques. IV. Nourriture du marsouin bloc ou beluga (*Dephinapterus leucas*) du fleuve Saint-Laurent. Dep. Pech., Quebec, 129 p.

[7]Brooks, J. W. 1954. Beluga. *In* 1954 Annual Rep., Alaska Dep. Fish Game, Juneau, p. 51–57.

[8]Brooks, J. W. 1955. Beluga. *In* 1955 Annual Rep., Alaska Dep. Fish Game, Juneau, p. 98–106.

[9]Klinkhart, E. G. 1966. The beluga whale in Alaska. Alaska Dep. Fish Game Rep., 11 p.

[10]Vania, J. 1967. Beluga. *In* 1966 Annual Rep., Alaska Dep. Fish Game, Juneau, p. 21–24

[11]Lowry, L. F., K. J. Frost, and G. A. Seaman. 1986. Investigations of belukha whales in coastal waters of western and northern Alaska. Part III. Food habits. Final Rep. U.S. Dep. Commer. NOAA, Anchorage, from Alaska Dep. Fish Game, 24 p.

[12]Hobbs, R. C., K. E. W. Shelden, D. J. Vos, K. T. Goetz, and D. J. Rugh. 2006. Status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Fish. Sci. Cent. Proc. Rep. 2006-16, 74 p.

[13]Alaska Dep. Fish Game. Unpubl. data on file at 1300 College Road, Fairbanks, AK 99701.

Figure 1.—Known summer areas used by five stocks of beluga whales in Alaska and the area within Kotzebue Sound where stock assignment is unclear. Belugas from the Beaufort Sea stock are harvested at Diomede and Point Hope while on spring migration and harvested in Canada in summer.

were measured to the nearest 0.1 mm and used to estimate cephalopod total body weight using an equation for a closely related species, *Octopus vulgaris* (Clarke, 1986).

For 17 stomachs from Cook Inlet beluga whales between 1992 and 2001, only a subsample of the stomach contents was collected, and only fresh or slightly digested material was identified. Few otoliths were recorded in these samples, but, diagnostic bones of fish were identified by Pacific Identifications Inc.[14], Victoria, British Columbia, Canada. No invertebrate prey items were recorded or identified.

We present fish prey in beluga stomachs as the percent number (% N) of fish by taxon by beluga whale stock. We determined the total number of fish identified in all fish taxa for all stomachs of that stock of beluga whale and then calculated the percentage of the total represented by each taxon. For example, if we estimated 100 individual fish from fish taxon A (e.g., saffron cod, *Eleginus gracilis*) and 300 fish from all fish taxa in all stomachs sampled from that beluga stock, then the % N of taxon A (saffron cod) for that stock was 100/300 or 33%. For invertebrates, % N was not calculated because we often could not determine the number of individuals from the parts available.

[14]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

The percent frequency of occurrence (% FO) is provided for all major prey types and was calculated for each stock as the number of stomachs containing that prey type divided by the total number of stomachs that contained any prey. For example, if 100 stomachs contained prey of any kind and 75 of those stomachs contained parts of echiurid worms, the % FO of echiurids would be 75%. Due to differential digestion rates, volume measurements were not considered representative of the true volume of prey consumed and were not analyzed.

Results

Our dataset includes 365 beluga whale stomachs, 233 of which had never been reported before, and 132 from unpublished ADFG reports. Stomachs from the ADFG studies included 22 collected in 1982 at Elephant Point (Eschscholtz Bay) in Kotzebue Sound (Lowry et al.[11]) and 109 collected in Bristol Bay during 1954 and 1955 (Brooks[7, 8]), 1965 and 1966 (Vania[10]), and in 1982 and 1983 (Frost et al., 1984), and one collected in Cook Inlet (Baxter and Baxter[15]). Of the 365 stomachs, 82 were empty (22%) or contained only nonfood items and 283 (78%) contained prey remains (Table 1).

Stomachs were collected from Cook Inlet to Barrow from 217 beluga whales harvested for subsistence, 102 collected for research, 41 found dead, and for 5 animals for which the type of death was not recorded. Most of the whales found dead were in Cook Inlet (n = 30; 73%).

Prior to 1982, beluga whales regularly occurred and were harvested in Kotzebue Sound. After 1982, occurrence became irregular and infrequent, and it is not known to what stock these belugas belonged. For this study, we considered stomachs collected from belugas in Kotzebue Sound to be Kotzebue Sound belugas, even though some of them may have been from other stocks.

Table 1.—Number of stomachs analyzed from Alaska's beluga whales belonging to five stocks and from a Kotzebue Sound population collected between 1954 and 2012.

Stock ID	Number of Stomachs		Month	Range of years	No. of years
	Total	Empty (%)			
Beaufort Sea	62	0 (0)	4–6	1983–2003	5
Eastern Chukchi Sea	67	37 (55)	6–8	1983–2010	13
Kotzebue Sound	29	7 (24)	6,7,10	1982–2008	3
Eastern Bering Sea	39	7 (18)	5–7,9,10	1993–2012	12
Bristol Bay	115	14 (12)	5–8,10	1954–2011	11
Cook Inlet	53	17 (32)	3–11	1961, 1992–2010	17
Total	365	82 (22)	3–11	1954–2012	30

For all locations in Alaska, a minimum total of 37 fish species and 40 invertebrate species were identified in beluga whale stomachs (Table 2, 3). Other species may have been present that we were not able to identify. Nonfood items included sand, pebbles, wood and other vegetation, kelp, feathers, and a piece of bone.

Beaufort Sea Stock

We analyzed stomach contents from 62 beluga whales from the Beaufort Sea stock collected between 1983 and 2003 at Point Hope and Diomede (Table 1). All were collected during April, May, and June. Sex was reported for all but one (19 males and 42 females) and length was reported for all but two. The mean length for males was 355 cm (range 203–462) and for females 332 cm (range 240–396) (Table 4). Twenty-one stomachs (34%) contained a minimum total of 418 fish of at least eight different species from five families (Table 2). The predominant species was Arctic cod, *Boreogadus saida*, which comprised 82% N and 21% FO (Table 2) and one stomach contained otoliths from 190 Arctic cod. Forty-one stomachs (66%) contained only invertebrates.

Otoliths from six fish species were measured to estimate the sizes of fish eaten. The largest fish were Arctic staghorn sculpin, *Gymnocantheus tricuspis*, with an estimated mean length of 17.9 cm (range 16.1–18.9), followed by shorthorn sculpin, *Myoxocephalus scorpius*, at 16.2 cm (range 12.1–18.5; Table 5). Arctic cod were next in estimated length (mean 14.2 cm, range 8.2–21.2) followed by walleye pollock, *Theragra chalcogramma*, and saffron cod, which were similar in estimated length at 10.7 cm (range 8.2–12.3) and 10.3 cm (range 7.6–16.3), respectively. Pacific sand lance, *Ammodytes hexapterus*, were the smallest with a mean length of 9.9 cm (range 8.1–11.3; Table 5).

Most stomachs (n = 57; 92%) contained invertebrates that represented 16 species from multiple taxonomic groups: predominately shrimp (60% FO), cephalopods (52% FO), echiurids (19% FO), and amphipods (11% FO; Table 3). Shrimp included at least five species from at least three families. All cephalopods were octopus (n = 358), 266 (74%) of which were identified as smoothskin octopus, *Benthoctopus leioderma* (Table 3). Three that were not identified to species were of the same genus and 89 were only recorded as octopus. The number of octopus per stomach ranged from 0 to 144 individuals, with two stomachs having >100 lower or upper octopus beaks each. Based upon 35 measurable beaks of 107 beaks present in a beluga stomach harvested near Point Hope in 1997, the average estimated weight per octopus was 1,015 g (SD = 442, range 140–1,965). The average estimated weight per octopus, calculated from 50 of 144 octopus beaks in a beluga whale harvested near Little Diomede in 2003, was 881 g (SD = 415, range 155–1,965).

Eastern Chukchi Sea Stock

Stomachs from 67 beluga whales from the eastern Chukchi Sea stock were collected between 1983 and 2010 (Table 1). Most (58 or 87%) were collected near Point Lay during June and July, and most (37 or 55%) were

[15]Baxter, R., and S. Baxter. 1961. Cook Inlet data report series 61-1, stream surveys west side Cook Inlet –1961. Alaska Dep. Fish Game, Homer, 43 p. + 10.

Table 2.—Percent number and percent frequency of occurrence of fish identified from stomach contents of beluga whales collected in Alaska by location, 1954–2012. Percent number is the number of fish from a taxa divided by the total number of all fish eaten (x 100). Percent frequency of occurrence is the number of stomachs that contained a fish taxon divided by the total number of stomachs that contained prey (x100).

	1983–2003 Beaufort		1983–2010 E. Chukchi		1982–2008 Kotzebue		1993–2012 E. Bering		1954–2005 Bristol Bay		2002–2010 Cook Inlet	
	Percent number $n = 21$	Percent frequency $n = 62$	Percent number $n = 9$	Percent frequency $n = 30$	Percent number $n = 21$	Percent frequency $n = 22$	Percent number $n = 21$	Percent frequency $n = 21$	Percent number $n = 99$	Percent frequency $n = 100$	Percent number $n = 17$	Percent frequency $n = 18$
Stomachs that contained fish (%)		34		30		95		100		99		94
Taxon — Stomachs that contained only fish (%)		8		7		5		10		76		50
Fishes												
All Petromyzontidae, lamprey spp.							<1	19	<1	3		
Arctic lamprey, *Lethenteron camtschaticum*							<1	19				
All Clupeidae					<1	5	1	24				
Pacific herring, *Clupea pallasii*					<1	5	1	24				
All Catostomidae											1	6
Longnose sucker, *Catostomus catostomus*											1	6
All Osmeridae	<1	2	7	3	3	55	14	67	16	43	12	11
Pond smelt, *Hypomesus olidus*									<1	1		
Rainbow smelt, *Osmerus mordax*			7	3	3	55	13	62	2	5		
Eulachon, *Thaleichthys pacificus*											12	11
Capelin, *Mallotus villosus*							<1	24				
All Salmonidae							<1	10	83	81	38	67
Dolly Varden, *Salvelinus malma*									<1	1		
Pink salmon, *Oncorhynchus gorbuscha*									<1	18		
Coho salmon, *Oncorhynchus kisutch*							<1	5	<1	10	21	28
Chinook salmon, *Oncorhynchus tshawytscha*									<1	3	2	11
Chum salmon, *Oncorhynchus keta*							<1	5	<1	15	8	17
Sockeye salmon, *Oncorhynchus nerka*									58	55		
All Gadidae	86	23	40	13	95	95	78	100	<1	3	42	39
Arctic cod, *Boreogadus saida*	82	21	7	3	–	–	29	43				
Saffron cod, *Eleginus gracilis*	1	5	20	7	94	95	48	95	<1	2	26	22
Walleye pollock, *Theragra chalcogramma*	3	3					<1	10			10	17
Pacific cod, *Gadus macrochephalus*											1	6
All Gasterosteidae, stickleback spp.	<1	2							<1	3		
All Cottidae	9	5			1	9	4	48	<1	6	1	6
Arctic staghorn sculpin, *Gymnocanthus tricuspis*	1	3					<1	5				
Sculpin species, *Hemilepidotus* spp.							<1	5				
Pacific staghorn sculpin, *Leptocottus armatus*											1	6
Belligerent sculpin, *Megalocottus platycephalus*							<1	19				
Shorthorn sculpin, *Myoxocephalus scorpius*	7	3					<1	14				
Sculpin species, *Myoxocephalus* spp.							<1	14				
Ribbed sculpin, *Triglops pingelii*							<1	5				
Sculpin species, *Triglops* spp.							3	5				
All Agonidae, poachers							<1	5				
All Liparidae							<1	14				
Variegated snailfish, *Liparis gibbus*							<1	14				
All Zoarcidae			13	3			<1	5				
Canadian eelpout, *Lycodes polaris*			13	3			<1	5				
All Stichaeidae					<1	5	<1	38	1	7	1	6
Stout eelblenny, *Anisarchus medius*							<1	5				
Slender eelblenny, *Lumpenus fabricii*					<1	5	<1	38				
Slender eelblenny or snake prickleback, *Lumpenus* spp.											1	6
All Ammodytidae	3	8	13	3	<1	5	<1	24				
Pacific sand lance, *Ammodytes hexapterus*	3	8	13	3	<1	5	<1	24				
All Pleuronectidae							2	48	<1	10	3	11
Pacific halibut, *Hippoglossus stenolepis*							<1	5				
Flathead sole, *Hippoglossoides elassodon*							<1	5				
Starry flounder, *Platichthys stellatus*											1	6
Northern rock sole, *Lepidopsetta polyxystra*							<1	14				
Unidentified rock sole, *Lepidopsetta* spp.									<1	1		
Longhead dab, *Limanda proboscidea*							<1	29				
Yellowfin sole flounder, *Limanda aspera*											2	11
Arctic flounder, *Pleuronectes glacialis*							<1	14				
All Unidentified fish	1	5	27	13			<1	14	<1	3	2	11
Minimum no. of fish species eaten (total = 37)	8		5		6		25		14		12	
Minimum no. of fish eaten	418		15		1,354		5,781		26,721		106	

empty. The other nine stomachs were from belugas harvested near Barrow in June, July, and August, none of which were empty. Although it is not entirely clear whether belugas near Barrow in summer belong to the Beaufort Sea or eastern Chukchi Sea stock, movements from satellite telemetry data suggest they are more likely to be eastern Chukchi Sea belugas (Fig. 1; Richard et al., 2001; Suydam et al., 2001).

Sex was known for all 67 belugas; 36 were males and 31 were females (Table 4). Mean body length for males (n = 26) was 390 cm (range 280–478) and for females (n = 25) was 349 cm (range 253–410). At least five species of fish from four families (Table 2), and 15 species of invertebrates from nine taxonomic groups were identified (Table 3). Of the 30 stomachs that contained food items nine (30%) contained fish for which the most prevalent species was saffron cod (7% FO).

Otoliths from three fish species were measured to estimate the sizes of fish

Table 3.—Percent frequency of occurrence of invertebrates identified from stomach contents of beluga whales collected in Alaska by location, 1954–2012. Percent frequency of occurrence is the number of stomachs that contained an invertebrate taxon divided by the total number of stomachs containing prey (x100).

	Percent frequency of occurrence					
	1983–2003 Beaufort $n = 62$	1983–2010 E. Chukchi $n = 30$	1982–2008 Kotzebue $n = 22$	1993–2012 E. Bering $n = 21$	1954–2005 Bristol Bay $n = 100$	2002–2010 Cook Inlet $n = 18$
Stomachs containing invertebrates (%)	92	93	95	90	24	50
Taxon — Stomachs containing only invertebrates (%)	66	70	5	0	1	6
Invertebrates						
All Porifera			5	5		6
All Polychaeta	5	17		38		11
Polynoidae		7		24		
Nereididae, *Nereis* spp.		7		10		
Pectinariidae				5		
All Bivalvia			5	33	3	
Astartidae, Astarte spp.				5		
Myidae				5		
Clinocardiinae, *Serripes groenlandicus*				5		
Tellinidae, *Tellina* spp.				5		
All Cephalopoda	52	10	5	10		
Squid, *Gonatus* spp.		3				
Minimum number of squid		3				
Octopus	42	7	5			
Benthoctopus leioderma, smoothskin octopus	8	3				
Benthoctopus spp.	2					
Minimum number of octopi	358	4	1			
All Gastropoda		7	36	10		
Polinices spp.			27			
All Cirripedia, barnacles	2					
All Mysidae			14	24		6
Mysis oculata				24		
Neomysis rayii				19		6
Neomysis spp.			14			
All Isopoda		3	36	38	4	
Saduria entomon			18	33	3	
Saduria spp.		3	18		1	
All Amphipoda	11	7	41	29		11
Ampeliscidae, *Ampelisca* spp.	2					
Byblis spp.	3					
Lysianassidae, *Orchomene* spp.						6
Uristidae, *Anonyx* spp.	2					
Senticaudata						
Anisogammaridae, *Anisogammarus pugettensis*	2					
Calliopiidae		3				
Gammaridae	3		14	5		
Gammarus spp.	2	3	27	19		
Melitidae, *Melita* spp.				5		
All shrimp	60	73	86	86	21	39
Caridea		3		29		17
Hippolytidae	2					
Eualus spp.	2					
Crangonidae	8	30		19		
Argis dentata	3					
Argis lar	3	3		5		
Argis spp.	13	30				
Crangon alaskensis or septemspinosa			32	29		6
Crangon franciscorum						6
Crangon spp.	11		59	10	2	6
Sclerocrangon boreas	2	23		5		
Pandalidae, *Pandalus* spp.	3					
All crabs	2	3		14	1	6
Majidae				5	1	
Oregoniidae, *Chionoecetes bairdi*						6
Chionoecetes opilio		3				
Hyas lyratus	2					
All Sipuncula		3				
All Echiuridae	19	27	5	29		6
All Bryozoa				10		
Clypeasteroida, sand dollar	2					
All Ascidiacea, tunicates		7		14		
Chelysoma spp.		3				
Pelonaia corrugata		7		5		
All unidentified invertebrates	3	10				6
Minimum no. of species eaten (total = 40)	16	15	9	22	4	8

eaten. The largest fish were saffron cod with an estimated mean length of 13.6 cm (range 6.5–20.7), followed by Pacific sand lance at 10.1 cm (range 9.7–10.5; Table 5). The otoliths from two Canadian eelpout, *Lycodes polaris*, were also measureable, but because no size or weight conversions have been developed for this species, fish size could not be estimated (Table 5).

Of the 30 stomachs that contained food items, 21 (70%) contained only invertebrates (Table 3). Shrimp occurred most often (73% FO), followed by echiurid worms (27% FO), poly-

chaetes (17% FO), and cephalopods (10% FO).

Between 1989 and 2010, 13 of 28 stomachs (46%) were reported to contain sand or "mud balls" but no food. Whether the mud was ingested incidentally or intentionally is unknown; however, stomachs with food usually had only minor amounts of nonfood items like sand and wood. In 2012, we examined stomach contents from two of the belugas harvested at Point Lay on 30 June 2009 where the contents appeared to be mostly fine grain sand; however, we found evidence of both fish and invertebrate prey. The first stomach was that of a white female and contained 3.9 kg of sand and parts of 63 tunicates (3 *Pelonaia corrugate*, 10 *Chelysoma* spp., and 50 unidentified to species), parts of at least 53 shrimp (all from the family Crangonidae, including 26 *Sclerocrangon boreas*), and 11 polychaetes (8 *Nereis* spp. and 3 from the family Polynoidea). The second stomach, that of a white-gray male, contained 2.1 kg of sand, and parts of 17 tunicates (7 *Pelonaia corrugate*, and 10 unidentified), at least 15 crangonid shrimp (including 5 *Sclerocrangon boreas*), and 4 otoliths; two each from saffron cod and Pacific sand lance. It is possible that stomachs visually inspected in the past and thought to contain only mud balls also contained invertebrates and otoliths mixed with the mud.

Table 4.—Sex and body length for some Alaska beluga whales belonging to five stocks and from a Kotzebue Sound population analyzed for stomach contents collected between 1954 and 2012.

Stock Location	Sex			Male body length (cm) *n*; mean (SD) range	Female body length (cm) *n*; mean (SD) range
	Male	Female	Unknown		
Beaufort Pt. Hope, Diomede	19	42	1	19; 355 (68.7) 203–462	41; 332 (32.0) 240–396
Eastern Chukchi Barrow, Pt. Lay	36	31	0	26; 390 (49.5) 280–478	25; 349 (30.9) 253–410
Kotzebue Escholtz Bay, Kotzebue	14	13	2	3; 304 (44.7) 257–345	5; 346 (27.5) 297–363
Eastern Bering Elim, Koyuk, Unalakleet, Hooper Bay	14	14	11	13; 389 (66.2) 279–475	9; 351 (66.9) 238–414
Bristol Bay	31	55	27	29; 333 (78.6) 187–470	47; 317 (49.2) 193–387
Cook Inlet	20	21	10	8; 391 (72.7) 256–463	15; 337 (67.1) 160–391

Kotzebue Sound

We analyzed stomach contents from 29 beluga whales harvested in Kotzebue Sound; 22 were harvested in June 1982 (two (9%) were empty), six were harvested in July 2007 (five (83%) were empty), and one was harvested in October 2008 (with food) (Table 1). Of 27 belugas where sex was known, 14 were males and 13 were females. Body lengths of three males averaged 304 cm (257, 310, and 345 cm) and five females averaged 346 cm (range 297–363) (Table 4). In 1982, stomach contents were identified and counted only from subsamples. For the more recent stomachs, all were analyzed completely but only two had contents. The only stomach with prey in 2007 contained a single gastropod operculum. The one stomach collected in 2008 contained both fish and invertebrates.

Of the 22 stomachs from Kotzebue with food, 21 contained fish (Table 2). At least six species of fish were identified representing six families. Saffron cod (95% FO) and rainbow smelt, *Osmerus mordax*, (55% FO) were most prevalent, followed by sculpins (9% FO). Pacific sand lance; Pacific herring, *Clupea pallasii*; and slender eelblenny, *Lumpenus fabricii*, were each represented at 5% FO (Table 2). Saffron cod were also numerically dominant; 1,279 of 1,354 (94% N) total fish eaten were saffron cod (Table 2).

Otoliths from 23 saffron cod were measured to estimate the average fish length at 23.8 cm (range 7.4–41.9; Table 5). One otolith from a Pacific sand lance provided a length estimate of 15.0 cm and two otoliths from rainbow smelt estimated fish lengths at 12.2 cm (range 11.1–13.2). One otolith from a slender eelblenny was measured but no conversion was available.

All but one stomach with food contained invertebrates (n = 21; 95%); including at least nine species. Shrimp was the dominant group (86% FO) followed by amphipods (41% FO); gastropods and isopods were represented equally at 36% FO (Table 3).

Eastern Bering Sea Stock

Stomach contents from 39 belugas from the eastern Bering Sea stock were collected between 1993 and 2012 during May (n = 17), June (n = 7), July (n = 1), September (n = 2), October (n = 9), and month unknown (n = 3). Seven of the 39 (18%) stomachs, six of which were collected in mid-June 1995, were empty (Table 1). Of 28 belugas where sex was known, the sex ratio was even at 14 each. Body length of 13 males averaged 389 cm (range 279–475), and nine females averaged 351 cm (range 238–414) (Table 4).

Stomachs from 11 beluga whales harvested near Elim in 1996 were only visually inspected and are not included in Tables 2 or 3: those stomachs contained saffron cod, and one also contained rainbow smelt. One of the 11 stomachs (9%) contained invertebrates, which were only identified as shrimp.

Of the 21 stomachs with food that were fully analyzed all contained cod: saffron cod (95% FO), Arctic cod (43% FO), and walleye pollock (10% FO; Table 2). In addition to cod, the overall fish diet by % FO included rainbow smelt (62%), several species of flounder and sculpin (both at 48%), slender eelblenny (38%), Pacific sand lance; capelin, *Mallotus villosus*; and Pacific herring (all at 24%); Arctic lamprey, *Lethenteron camtschaticum* (19%); snailfish (14%); and two species of salmon (coho, *Oncorhynchus kisutch*; and chum, *O. keta*, each at 5%). Nine stomachs contained evidence of >100 individual saffron cod (range 121–474). Overall, a minimum of 25 species of fish from 12 families were identified (Table 2).

Table 5.—Mean, standard deviation (SD), and range of otolith lengths (mm), fish length (cm), and weight (g) of fish collected from beluga whale stomachs. Fish length and weight were converted from equations or measured directly from whole fish.

Fish	Beluga stock	*n*	Mean otolith length in mm (SD) range	Mean fish length in cm (SD) range	Mean fish weight in g (SD) range	Source of equation
Clupeidae						
Pacific herring	E. Bering	18	4.9 (0.5) 4.0–5.8	24.1 (2.8) 19.1–28.5	228.6 (85.5) 99.4–388.3	Harvey et al., 2000
Osmeridae						
Pond smelt	Bristol Bay	2	2.7 (0.4) 2.4–3.0			No conversion available
Rainbow smelt	Kotzebue	2	4.4 (0.6) 4.0–4.8	12.2 (1.5) 11.1–13.2	14.1 (5.6) 10.1–18.0	Harvey et al., 2000
	E. Bering	233	5.0 (1.0) 2.0–9.5	13.9 (2.8) 5.7–25.9	24.6 (19.1) 1.1–162.6	Harvey et al., 2000
	Bristol Bay	6	5.0 (1.8) 1.4–6.2	13.7 (5.0) 4.1–17.0	27.0 (15.7) 0.4–41	Harvey et al., 2000
	Bristol Bay	2		19.6 (2.8) 17.6–21.5	67.3 (30.1) 46.0–88.6	Length measured Weight Harvey et al., 2000
	Bristol Bay	1			53.1 (NA)	Measured
Eulachon	Cook Inlet	4	4.3 (0.3) 3.9–4.5	17.4 (1.2) 15.7–18.5	51.2 (10.5) 36.4–60.6	Harvey et al., 2000
Capelin	E. Bering	5	2.5 (0.3) 2.3–3.0	12.4 (0.9) 11.6–14.0	15.6 (4.0) 12.3–22.4	Harvey et al., 2000
Salmonidae						
Coho salmon	Cook Inlet	10	4.9 (0.2) 4.5–5.2			
	Cook Inlet	3		62.1 (2.6) 58.3–64.1	3,124 (357) 2,747–3,476	Measured
Chum salmon	Cook Inlet	4	5.4 (0.2) 5.2–5.5			
	Cook Inlet	5		60.0 (3.8) 56.0–65.0	2,989 (600) 2,275–3,661	Measured
Sockeye salmon	Bristol Bay	2	5.4 (1.6) 4.3–6.5	64.4 (13.4) 54.9–73.8	3,478 (2,493) 1,715–5,240	Measured
Gadidae						
Arctic cod	Beaufort	84	5.9 (1.3) 3.0–8.9	14.2 (2.9) 8.2–21.2	24.6 (16.0) 2.8–78.3	Frost and Lowry, 1981
	E. Bering	467	5.9 (0.5) 4.7–7.3	14.5 (1.0) 11.9–17.6	21.5 (5.3) 10.5– 41.4	Frost and Lowry, 1981
Saffron cod	Beaufort	4	5.9 (2.2) 4.4–9.1	10.3 (4.0) 7.6–16.3	9.7 (12.4) 2.6–28.2	Frost and Lowry, 1981[1]
	E. Chukchi	2	7.4 (5.1) 3.8–11.0	13.6 (10.0) 6.5–20.7	30.5 (40.7) 1.7–59.3	Frost and Lowry, 1981[1]
	Kotzebue	23	12.1 (5.2) 4.3–20.1	23.8 (11.3) 7.4–41.9	151.6 (142.7) 2.4–522.7	Frost and Lowry, 1981[1]
	E. Bering	558	10.3 (2.2) 4.9–17.6	19.3 (4.8) 8.4 – 36.0	56.9 (41.7) 3.7–329.2	Frost and Lowry, 1981[1]
	Bristol Bay	1	4.2 (NA)	7.2 (NA)	2.3 (NA)	Frost and Lowry, 1981
	Cook Inlet	3	11.5 (3.3) 7.7–13.4	18.9 (6.2) 11.8–22.6	77.6 (55.8) 13.1–111.3	Harvey et al., 2000
Walleye pollock	Beaufort	3	5.0 (1.0) 3.9–5.7	10.7 (2.2) 8.2–12.3	8.1 (4.1) 3.5–11.3	Frost and Lowry, 1981
	E. Bering	1	4.2 (NA)	8.9 (NA)	4.5(NA)	Frost and Lowry, 1981
Cottidae						
Arctic staghorn sculpin	Beaufort	4	5.6 (0.3) 5.1–5.8	17.9 (1.2) 16.1–18.9	56.8 (11.3) 40.7–66.3	Seaman et al., 1982[2]
Belligerent sculpin	E. Bering	7	6.8 (0.7) 6.2–7.8	23.0 (2.7) 20.5–26.9	125.2 (45.0) 84.9–194.3	Seaman et al., 1982[2]
Shorthorn sculpin	Beaufort	17	5.1 (0.5) 4.1–5.7	16.2 (2.0) 12.1–18.5	43.0 (14.3) 17.0–62.1	Seaman et al., 1982[2]
	E. Bering	4	6.1 (0.6) 5.4–6.6	20.2 (2.3) 17.3–22.1	83.7 (27.8) 50.6–106.8	Seaman et al., 1982[2]
Stichaeidae						
Stout eelblenny	E. Bering	1	1.4 (NA)			No conversions available
Slender eelblenny	Kotzebue	1	2.2 (NA)			No conversions available
	E. Bering	9	2.5 (0.3) 2.1–2.9			No conversions available
Liparidae						
Variegated snailfish	E. Bering	2	2.7 (0.1) 2.6–2.8			No conversions available
Zoarcidae						
Canadian eelpout	E. Chukchi	2	5.9 (0.5) 5.5–6.2			No conversions available
Ammodytidae						
Pacific sand lance	Beaufort	3	1.9 (0.4) 1.5–2.3	9.9 (1.6) 8.1–11.3	3.9 (1.7) 2.2–5.5	Harvey et al., 2000
	E. Chukchi	2	2.0 (0.1) 1.9–2.1	10.1 (0.6) 9.7–10.5	4.0 (0.6) 3.6–4.5	Harvey et al., 2000
	Kotzebue	1	3.2 (NA)	15.0 (NA)	12.0 (NA)	Harvey et al., 2000
	E. Bering	1	1.7 (NA)	8.9 (NA)	2.8 (NA)	
Pleuronectidae						
Longhead dab	E. Bering	3	3.1 (0.6) 2.5–3 6			No conversions available
Arctic flounder	E. Bering	3	4.3 (0.2) 4.1–4.4			

[1]There are two different length regressions in Frost and Lowry (1981) for this species depending on otolith size.
[2]The length and weight regressions from Seaman et al. (1982) are the same for all Cottidae species.

The average estimated lengths of fish, from largest to smallest, was Pacific herring (24.1 cm, range 19.1–28.5); belligerent sculpin, *Megalocottus platycephalus* (23.0 cm, range 20.5–26.9); shorthorn sculpin (20.2 cm, range 17.3–22.1); saffron cod (19.3 cm, range 8.4–36.0); Arctic cod (14.5 cm, range 11.9–17.6); rainbow smelt (13.9 cm, range 5.7–25.9); and capelin (12.4 cm, range 11.6–14.0). Walleye pollock and Pacific sand lance each had one otolith with an estimated fish length of 8.9 cm. Otoliths were measured for several other species for which conversions were not available to estimate length (Table 5).

Of the 21 stomachs that contained food items, 19 (90%) contained invertebrates. At least 22 species of invertebrates were represented, of which shrimp was predominant at 86% FO followed by polychaetes and isopods at 38% FO each, then bivalves at 33% FO, echiurids and amphipods at 29% FO each, mysids at 24% FO, crab and tunicates at 14% FO; gastropods, cephalopods, and bryozoans were each represented at 10% FO (Table 3).

Three of the belugas, whose stomach contents are included above, were caught in the same net near Elim, in Norton Sound, on 30 Sept. 2000. One was an adult male (357 cm) and two were smaller females (238 and 245 cm). All three stomachs contained Arctic cod and saffron cod, but the male had also eaten two adult salmon (one coho and one chum); the female stomachs had no salmon but contained other smaller fish (e.g., slender eelblenny, smelt, sculpin) and the larger female's stomach also contained shrimp and cephalopods.

Six stomachs were collected on 27 Oct. 2012 in Hooper Bay, one white male and five females (one white, three white-gray, and one dependent calf). These belugas were part of a larger group of about 80 belugas that hunters noted were after fish, possibly cod (Simon[16]). Five of these stomachs contained a wide variety of fish and invertebrates (Table 6). The sixth stomach, from the calf, was empty.

Table 6.—Number and type of prey identified from stomach contents of five belugas from the eastern Bering Sea stock collected in Hooper Bay, Alaska, on 27 October 2012.

	Beluga stomach				
	1	2	3	4	5
Taxon / Gender / Color	Male White	Female White	Female White-gray	Female White-gray	Female White-gray
Fishes					
All Petromyzontidae, lamprey spp.					
Arctic lamprey, *Lethenteron camtschaticum*	3		2	2	11
All Osmeridae					
Rainbow smelt, *Osmerus mordax*	41	174	128	200	203
Capelin, *Mallotus villosus*		4	9	7	1
All Gadidae					
Arctic cod, *Boreogadus saida*	78	347	399	440	380
Saffron cod, *Eleginus gracilis*	181	242	390	83	147
All Cottidae					
Sculpin species, *Hemilepidotus* spp.		1			
Belligerent sculpin, *Megalocottus platycephalus*		4	9	4	5
Sculpin species, *Myoxocephalus* spp.	1	2			2
All Liparidae					
Variegated snailfish, *Liparis gibbus*		1	4	1	
All Zoarcidae					
Eelpout species, *Lycodes spp.*			2		
All Stichaeidae					
Stout eelblenny, *Anisarchus medius*				1	
Slender eelblenny, *Lumpenus fabricii*	1	1	1	4	1
All Ammodytidae					
Pacific sand lance, *Ammodytes hexapterus*		1	2	1	2
All Pleuronectidae					
Longhead dab, *Limanda proboscidea*		4	2	2	1
Arctic flounder, *Pleuronectes glacialis*		1	3		
All Unidentified fish				4	
Minimum no. of fish eaten	305	782	951	749	753
Invertebrates					
All Polychaeta					
Polynoidae	18	11	19	8	8
Nereididae, *Nereis* spp.	11			2	
All Bivalvia		3			
All Mysidae					
Mysis oculata	1	9	12	10	9
Neomysis rayii		5	3	2	1
All Isopoda					
Saduria entomon	1	3	4	1	1
All Amphipoda					
Gammaridea	3				
Gammarus spp.			10		5
Melitidae, *Melita* spp.		1			
All shrimp					
Crangon alaskensis or septemspinosa	1	50	60	40	35
Shrimp spp.	20				
All Ascidiacea, tunicates					
Pelonaia corrugata		1			
Minimum no. of taxon eaten	13	20	18	18	16

Bristol Bay Stock

Stomach contents from 115 beluga whales from the Bristol Bay stock were collected between 1954 and 2011 in May (n = 25), June (n = 31), July (n = 32), August (n = 26), and October (n = 1). Of the 115 stomachs, 14 (12%) were empty (Table 1). Of the 101 stomachs that contained prey 100 (99%) contained fish. One beluga stomach from August 2010 was only visually inspected and is not included in Table 2; this stomach was reported to be full of adult coho salmon.

The dominant fish family was Salmonidae (81% FO and 83% N), with all five salmon species identified (Table 2). Sockeye, *Oncorhynchus nerka*, was the most prevalent species (55% FO and 58% N) followed by pink, *O. gorbuscha*, (18% FO), chum (15% FO), coho (10% FO), and Chinook, *O. tshawytscha*, (3% FO). Osmeridae, the smelt family, was the only other prevalent family (43% FO), with rainbow smelt the majority by species. Although Table 2 shows rainbow smelt only representing 5% FO of the 43% FO of all smelt, most smelt were not reported by species in the early data. It is likely that the majority of these

[16]Simon, A., Native Village of Paimiut, P.O. Box 91, Hooper Bay, AK 99604. Personal observ.

unidentified smelt were rainbow smelt as they are the predominant species in Bristol Bay. Evidence of more than 300 smelt per stomach was found in seven stomachs (range 368–710 individuals). Other stomachs with large numbers of fish included 14 stomachs with >500 salmon smolts (range 531–2,798) and four stomachs with seven or more adult sockeye salmon (range 7–9).

At least 14 different species from eight fish families were represented in Bristol Bay beluga stomachs during this time (Table 2). The lengths of two sockeye salmon were measured at 54.9 and 73.8 cm. The lengths of two rainbow smelt were measured at 17.6 and 21.5 cm, whereas the lengths of six rainbow smelt estimated from otoliths averaged 13.7 cm (range 4.1– 17.0) (Table 5).

Of the 101 stomachs that contained prey, 24 stomachs (24%) contained invertebrates from at least four species from four taxonomic groups. Shrimp was the most dominant invertebrate (21% FO), followed by isopods (4% FO) and bivalves (3% FO). A few shrimp were identified as crangonids, however, most were recorded only as shrimp (Table 3).

Cook Inlet Stock

A total of 53 stomachs were analyzed from Cook Inlet (Table 1); however, stomachs collected between 1992 and 2001 (n = 24) were analyzed separately from stomachs collected between 2002 and 2012 (n = 28). Contents were only visually inspected and not quantified during the earlier time period, whereas entire stomachs were analyzed and all identifiable prey items enumerated during the later time period. The contents of one stomach from one female beluga killed near the mouth of the Katnu River in 1961 was reported by Baxter and Baxter[17] to include Dolly Varden, *Salvelinus malma;* Pacific staghorn sculpin, *Leptocottus armatus*; "gray sand shrimp" (likely a crangonid shrimp species), and other unidentifiable fish remains. Only data from complete stomachs collected from 2002 to 2012 appear in Tables 2 and 3.

Stomachs from the earlier time period (1992–2001) were collected between April and October; 7 of the 24 (29%) were empty. Eulachon, *Thaleichthys pacificus*, and Chinook salmon were the only prey identified to species during this time period. No invertebrates were reported in those stomachs with prey, however, cursory visual inspections could have missed invertebrate remains. We believe that invertebrates were part of the diet during this time period, but they were not identified or reported. Empty stomachs occurred in summer and fall. Of the 24 belugas sampled, 16 belugas were harvested, 5 were found dead, and for 3 the cause of death was unrecorded.

Twenty-eight stomachs analyzed during 2002–2012 were collected between March and November. Ten of 28 stomachs (36%) were empty; one collected in June, two in August, two in September, four in October, and one in November. Of the 18 stomachs with food 17 (94%) contained fish remains and 9 (50%) contained invertebrates (Tables 2, 3). Three beluga whales were harvested, 24 were found dead, and for one the type of death was unrecorded. A minimum of 12 fish species and 8 invertebrate species were identified (Tables 2, 3).

The 12 fish species represented seven families (Table 2). Salmon (67% FO), cod (39% FO), smelt (11% FO), and flounder (11% FO) were most prevalent (Table 2). Salmon that could be identified to species included coho (28% FO, 21% N), chum (17% FO, 8% N), and Chinook (11% FO, 2% N). Cod species included saffron cod (22% FO, 26% N), walleye pollock (17% FO, 10% N), and Pacific cod, *Gadus macrochephalus* (6% FO, 1% N). Eulachon (11% FO 12% N) was the only smelt identified, and yellowfin sole, *Limanda aspera* (11% FO, 2% N) and starry flounder, *Platichthys stellatus* (6% FO, 1% N) were the only flounders. One longnose sucker, *Catostomus catostomus*, was the only freshwater fish found.

Salmon were the largest fish eaten by Cook Inlet beluga whales. Coho salmon averaged 62.1 cm (range 58.3–64.1) in length, and chum salmon averaged 60.0 cm (range 56.0–65.0) (Table 5). Other fish in which lengths could be estimated included saffron cod (18.9 cm, range 11.8–22.6), and eulachon (17.4 cm, range 15.7–18.5) (Table 5). For three beluga whale stomachs that were relatively full when collected one contained 12 whole coho salmon (27.8 kg), the second had five whole chum salmon (15.6 kg), and the third had three whole coho salmon and two partially digested salmon of unidentified species (15.0 kg).

Shrimp, polychaetes, and amphipods made up the bulk of the invertebrate prey. Of the 18 stomachs that contained prey, 9 (50%) contained eight species of invertebrates, predominantly shrimp (39% FO), followed by polychaetes and amphipods, each represented at 11% FO (Table 3).

Discussion

Data Limitations

Diet studies using stomach contents have well known biases (Tollit et al., 2010; Bowen and Iverson, 2012). Stomach contents represent some portion of an individual's most recent feeding activity. Small and soft parts digest more quickly and completely (Sheffield et al., 2001), which in our dataset could result in an under-representation of prey such as polychaetes and salmon smolts. Hard parts (e.g., otoliths and cephalopod beaks) can remain in the stomach longer and can accumulate through several feedings (Jobling and Breiby, 1986), which can result in an over-representation of prey such as saffron cod (large otoliths) and octopus (beaks tend to adhere to stomach lining and are resistant to digestion: Pitcher, 1980; Bigg and Fawcett, 1985). Stomachs collected from belugas found dead may be less likely to contain prey than harvested belugas; if the animals were sick or injured they may not have been feeding normally prior to death. Because most of the nonharvested belugas came from Cook Inlet, this concern mostly applies to that stock.

In addition to biases due to differen-

tial feeding and digestion, seasonality of prey (relative to the time of sampling), individual prey preferences, and perhaps other factors we have not identified may also affect results of diet studies. For example, adult salmon runs occur at specific times of year, and some species are available over a longer period of time than others. Many of the stomachs we examined were from belugas harvested by subsistence hunters. Thus, the timing of sample collection was often linked to the timing of subsistence activities.

Depending upon when stomachs are collected, what is present (or not present) in them will vary. If no stomachs were collected during a particular time of year, prey species specific to that time of year would be missing from our analysis. Samples from the subsistence harvest were collected in spring, summer, and fall when people hunt, and samples from belugas found dead were collected in summer and fall when people are most likely to observe and respond to them. Furthermore, there appears to be considerable variation in diet among individuals. For example, the three belugas that were caught in the same net on the same night near Elim in the eastern Bering Sea each contained different food items.

In spite of such biases, stomach contents collected from the harvest and from belugas found dead provide valuable information regarding prey consumed (often identified to species), and the number and frequency of their occurrence. With adequate samples sizes, stomach content data provide valuable information about the diet of each stock. Other methods of diet analysis (e.g., stable isotopes and fatty acids) result in qualitative information regarding trophic level and general categories of prey. Quantitative information from these indirect approaches require complete prey libraries (often difficult to obtain) in order to interpret diet to the species level (Budge et al., 2006; Newsome et al., 2010).

Non-feeding Periods

Beluga whales in some areas of Alaska are known to eat large amounts of fish in spring and summer, although it is not known if other activities take precedence over feeding during this time or how much feeding occurs in winter. Most stomachs (66%) collected from Point Lay (eastern Chukchi Sea stock) were empty. These belugas were harvested in June and July when migrating, molting, calving, or other behavior may have been more important than feeding. Histological studies of liver and pancreas tissue from belugas harvested at Point Lay indicated that they were likely fasting prior to harvest (Woshner, 2000). Belugas may fast during the annual skin molt.

Another reason belugas may have empty stomachs, in addition to illness or injury, may be due to the avoidance of marine mammal-eating killer whales, *Orcinus orca*. Belugas harvested in Kotzebue Sound in July 2007 were believed to be avoiding killer whales because they would not leave shallow water even while being approached by boats to be hunted; five of six stomachs examined were empty, and one contained only one operculum from a gastropod. Belugas sometimes regurgitate food when being chased (Quakenbush[5]), which could result in empty stomachs at the time of sampling.

In Bristol Bay, Lensink[3] found that in early June, beluga stomachs were mostly empty. Six stomachs collected during 6–15 Jun. 1959 and 1960 were empty except for a few shrimp fragments, indicating there may be a period of reduced feeding after salmon smolts migrate to sea and before adult salmon are available. Lensink[3] also reported that eight beluga stomachs collected during 11–25 Sept. 1959 and 1960 contained only small quantities of shrimp, small flatfish, and a lamprey, possibly indicating another reduced feeding period after adult salmon runs end in the fall. Very few stomachs were collected in fall and winter for any beluga stock in Alaska.

Comparison with Other Studies

Prior to this study, Seaman et al. (1982) provided the most complete information on beluga whale diet in Alaska. At the time it was published, diet data for Cook Inlet belugas were not available. Our study identified 34 fish prey to species, one sculpin to genus, *Hemilephidotus*, and two that could only be identified to family; Gasterosteidae (sticklebacks), and Agonidae (poachers). Fish eaten by belugas in our study that were not found by Seaman et al. (1982) included Arctic lamprey, pond smelt, *Hypomesus olidus*; eulachon, capelin, five species of Pacific salmon, Pacific cod, walleye pollock, poachers, variegated snailfish, eelblenny, and Pacific sand lance. We did not identify any whitefish, *Coregonus* sp., in our study, which were found by Seaman et al. (1982) and by Huntington (2000). While Seaman et al. (1982) reported the general categories of flatfish and sculpin as prey; we identified seven flatfish and six sculpin to species (Table 2). Two of the species identified in our study alone were found exclusively in Cook Inlet: eulachon and Pacific cod.

Although capelin are sometimes observed in large concentrations near Point Lay and Barrow and are likely important to belugas wherever they are available (Suydam[17]) we only found them in five stomachs from the Eastern Chukchi Sea stock, and they were not found by Seaman et al. (1982). Capelin may be an example of a prey species that has a strong regional and seasonal component that our opportunistic collection regime does not often detect.

We identified invertebrates that were not found by Seaman et al. (1982), including several additional taxa of amphipods, shrimps, crabs, and bivalves. Our findings relative to cephalopods were similar in that more octopus than squid was eaten (Table 3). Some of the invertebrates found in beluga stomachs could be due to secondary ingestion, because sculpin and saffron cod eat shrimp, amphipods, crabs, and polychaetes. Seaman et al. (1982) considered octopus, shrimp, and some-

[17]Suydam, R., North Slope Borough, P.O. Box 69, Barrow, AK 99723. Personal observ.

times isopods to be directly consumed by belugas.

By looking at stomachs with no fish remains (n = 65), we found that polychaetes, gastropods, cephalopods, isopods, amphipods, shrimp, echiurids, and tunicates were present and were likely ingested directly as prey by beluga whales. Echiurid setae are commonly found in beluga stomachs, appear to be resistant to digestion, and may have delayed passage through the stomach. Evidence of echiurids was found in stomachs from all stocks, except Bristol Bay, in this study.

Our findings that the predominant fish species of the Beaufort Sea stock was Arctic cod was also found by Loseto et al. (2009) using fatty acid analysis. Overall however, we found invertebrates in more stomachs than fish; 66% of all stomachs contained invertebrates only. Loseto et al. (2009) did not find invertebrates to be important prey relative to the importance of Arctic cod.

Regional Differences

Stocks were sampled during different seasons making seasonal comparisons difficult. A comparison of the overall diet of the different stocks, however, showed that the northernmost migratory stock (Beaufort Sea) predominantly fed on shrimp (60% FO), octopus (42% FO), and Arctic cod (21% FO). The eastern Chukchi Sea stock fed mostly on shrimp (73% FO), echiurids (27% FO), polychaetes (17% FO), and saffron cod (7% FO). The eastern Bering Sea stock and Kotzebue belugas fed mostly on saffron cod (both 95% FO) and shrimp (both 86% FO). Six other invertebrate taxa were notable for the eastern Bering stock; polychaetes and isopods each at 38% FO, bivalves at 33%, echiuriids and amphipods each at 29% FO, and crabs and tunicates each at 14% FO. In addition to shrimp, four other invertebrate taxa were prominent for Kotzebue belugas; amphipods (41% FO), gastropods and isopods each at 36% FO, and mysids at 14% FO. The two nonmigratory stocks (Bristol Bay and Cook Inlet) were the stocks in which most salmon were found, but they also ate smelt, cod, and shrimp; although invertebrates appeared to be much less important compared to the other stocks (Table 3).

Prior to 2002, Cook Inlet beluga stomachs were not completely analyzed, and therefore less information is available for this time period, especially regarding invertebrate prey. Although Chinook salmon was identified in one of the earlier stomach samples and subsistence hunters reported 19 adult Chinook salmon in one harvested beluga (Huntington, 2000), we only identified Chinook salmon in two stomachs sampled after 2002 (n = 18). The main Chinook salmon runs in Cook Inlet occur April–July (Barrett et al.[18, 19]; McKinley and Fleischman[20, 21]). Six of the 18 stomachs we analyzed after 2002 were collected during this time period, and therefore could have contained Chinook salmon.

Otoliths of all species of salmon are small and degrade easily, making identification of salmon to species more difficult. Similarly, in Bristol Bay where all five salmon species are available, Chinook salmon were the least represented in the beluga diet, but again this may be due to the difference in the timing of collections relative to timing of specific salmon runs.

Other Differences

In addition to the seasonality of prey availability, prey size may also influence diet. Beluga whales swallow their prey whole (Brooks[8]; this study), thus smaller (i.e., young) belugas are limited by the size of their esophagus to smaller prey (Fay, 1971). Brooks[8] found that unweaned calves ate small bottomfish and shrimp. Yearlings mainly ate smaller fish and few adult salmon. Therefore, many Chinook, and some chum and coho salmon, may be too large for smaller belugas to eat, thereby limiting the suitability of some adult salmon as prey even when they are available.

Our sample sizes of beluga sex and length, and fish length did not allow us to analyze diet by beluga sex or age class, although subadult belugas have been found to eat more invertebrates, while adult females ate smaller fish and adult males ate larger fish (Seaman et al., 1982).

On the other hand, all sizes of belugas likely eat salmon smolts during smolt migration to the sea. Although not represented in any samples, salmon smolts are known to be important to Bristol Bay belugas in the spring (Brooks[7, 8]) and may be important to Cook Inlet belugas as well.

Prior to 2002 in Cook Inlet, more beluga stomachs were collected from harvested animals, while after 2002, more stomachs were collected from stranded animals due to the restricted harvest. No invertebrates were recorded in the earlier sample of Cook Inlet beluga stomachs. This is most likely due to an artifact of the field methods used to determine diet. Stomach contents appeared to have been examined in a more cursory fashion that may have resulted in invertebrate prey items being missed. Although not detecting invertebrates in the earlier stomach samples does not necessarily change the number of fish species eaten, it does indicate the difference in the methods used to analyze diet could have influenced the fish results as well. Seasonal distribution of stomachs was similar for both time periods.

Beluga distribution within Cook Inlet has been shifting to the upper Inlet from a broader distribution that more regularly included the lower (Kachemak Bay) and the mid-inlet (Rugh et

[18]Barrett, B. M., F. M. Thompson, and S. N. Wick. 1984. Adult anadromous fish investigations: May–October 1983. Sustina Hydro Aquatic Studies. Rep. No. 1. Alaska Dep. Fish Game, Anchorage.

[19]Barrett, B. M., F. M. Thompson, and S. N. Wicks. 1985. Adult salmon investigations: May–October 1984. Susitna Aquatic Studies Program. Rep. No. 6. Alaska Dep. Fish Game, APA Doc. No. 2748, Anchorage.

[20]McKinley, T. R., and S. Fleischman. 2010a. Stock assessment of late-run Chinook salmon in the Kenai River, 1999–2006. Alaska Dep. Fish Game, Fishery Data Series No. 10-96, Anchorage.

[21]McKinley, T. R., and S. Fleischman. 2010b. Stock assessment of early-run Chinook salmon in the Kenai River, 1999-2006. Alaska Dep. Fish Game, Fishery Data Series No. 10-19, Anchorage.

al., 2000). Belugas used to feed on herring in Kachemak Bay prior to the late 1920's when herring declined there (Rounsefell, 1930). In April, hunters from Nanwalek would harvest belugas when they fed on herring in Halibut Cove within Kachemak Bay (Rounsefell, 1930; Stanek, 1994). The distributional shift to the upper Inlet could be due to fewer belugas available to fill the historic habitat, the upper Inlet becoming better habitat, or the lower Inlet becoming poorer habitat. Fewer fish, however, does not explain why belugas use the Kenai River less than in the past, because salmon runs there are believed to be at least as large as those in the Susitna River in the upper Inlet (McKinley and Fleischman[20,21]). Other activities, such as a commercial beluga harvest in the 1960's (Mahoney and Shelden, 2000) and increased boat traffic, may be factors in the decline in use of the Kenai River area.

The two nonmigratory stocks, Cook Inlet and Bristol Bay, have several things in common that may allow them to be resident year-round. Both regions are large, tidally influenced estuarine systems with multispecies salmon runs and shallow-water habitat for escape from killer whales. Both regions also have an abundance of smelt, although eulachon in Cook Inlet may be more seasonally restricted than rainbow smelt in Bristol Bay.

The tides in both areas keep the sea ice broken all winter, which allows belugas access to the bays, but the floating ice restricts killer whale access in winter. Beluga whales do not have a dorsal fin (an advantage for surfacing in sea ice), and they can swim and feed in very shallow, muddy water (<1 m). These adaptations and their distribution may serve as defenses against killer whales (Frost and Lowry, 1990). Killer whales appear to avoid ice likely because their large dorsal fin limits their ability to surface and breathe in broken ice covered water (Matthews et al., 2011; Higdon et al., 2012). The migratory stocks of belugas may rely on sea ice as escape habitat while the resident stocks may rely on shallow water. In addition to food, habitat selection may also involve molting and calving areas, protection from killer whales, and human activity.

Although the eastern Bering Sea stock also has access to large multispecies salmon runs in summer in the Yukon-Kuskokwim Delta and Norton Sound areas, these areas freeze more completely in winter due to weaker tides that are unable to keep the ice broken. It is not clear why more salmon were not found in stomachs of belugas from the eastern Bering Sea, but it may be due to timing of harvests and the importance of commercial fishing in the area. Some hunters may be fishing instead of pursuing belugas at a time when salmon may be an important prey item. It is clear that the migratory stocks of belugas take advantage of the seasonal abundance of forage fish nearshore in summer.

Beluga whales were harvested regularly and in significant numbers in Kotzebue Sound prior to 1982 (e.g., Eschscholtz Bay belugas from Seaman et al.[22] came from this harvest). After 1983, 10 or fewer belugas have been harvested in the sound in most years (Frost and Suydam, 2010). However, two unusual events have occurred resulting in high harvests, one in 1996 and another in 2007. The belugas harvested in 1996 were genetically similar (using mtDNA) to those harvested in the late 1970's and early 1980's; however, those harvested in 2007 were not (O'Corry-Crowe[23]).

Few belugas have been seen or harvested near Kotzebue in recent years; however, in July 2007 a large group (~150) of mostly adult male belugas went deep into Kotzebue Sound, and many were harvested. The genetic (mtDNA haplotypic) composition of this group was distinct from all previously sampled beluga whale groups from Kotzebue Sound. As a group, the whales harvested in 2007 had very strong genetic similarities (mtDNA and nDNA) to the Beaufort Sea stock. Genetic analysis is ongoing to determine whether the 2007 belugas were from the Beaufort Sea stock, were a mix of two or more stocks of whales, or were from a previously unidentified stock (O'Corry-Crowe[23]).

Interspecies Overlap in Diet

Interspecies overlap in fish prey is most likely to occur among belugas and seals, although other possibilities include Steller sea lions, *Eumetopias jubatus,* and harbor porpoises, *Phocoena phocoena*, in some areas. The Beaufort Sea, eastern Chukchi Sea, and eastern Bering Sea beluga stocks likely overlalp with ringed, *Pusa hispida*, and spotted, *Phoca largha,* seals, for all fish species (Gol'tsev, 1971; Bukhtiyarov et al., 1984; Quakenbush et al.[24, 25]) and with bearded seals, *Erignathus barbatus*, for Pacific sand lance, Arctic cod, saffron cod, sculpins, eelblenny, and flatfish (Kosygin, 1971; Lowry et al., 1980; Antonelis et al., 1994; Quakenbush et al.[26]). In Bristol Bay, the most abundant seals are spotted and harbor, *Phoca vitulina*, seals and in Cook Inlet, only harbor seals are present. Overlap with fish species important to humans is also possible for the eastern Bering Sea, Bristol Bay, and Cook Inlet stocks where commercial and subsistence fisheries for herring and salmon exist.

Interspecies overlap for invertebrate prey is most likely to occur among

[22]Seaman, G. A., K. J. Frost, and L. F. Lowry. 1985. Investigations of belukha whales in coastal waters of western and northern Alaska. Part I. Distribution, abundance and movements. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 56:153–220 (avail. from NOAA-OMA-OAD, Alaska Office, 701 C. Street, P.O. Box 56, Anchorage, AK 99513).

[23]O'Corry-Crowe, G., Fl Atl. Univ., Harbor Br., 5600 U.S. 1 North, Fort Pierce, FL 34946. Personal commun., July 2012.

[24]Quakenbush, L., J. Citta, and J. Crawford. 2009. Biology of the spotted seal (*Phoca larga*) in Alaska from 1962 to 2008. Prelim. Rep. Natl. Mar. Fish. Serv., Natl. Mar. Mammal Lab., Seattle, 66 p.

[25]Quakenbush, L., J. Citta, and J. Crawford. 2011a. Biology of the ringed seal (*Phoca hispida*) in Alaska, 1960–2010. Final Rep. Natl. Mar. Fish. Serv., Natl. Mar. Mammal Lab., Seattle, 72 p.

[26]Quakenbush, L., J. Citta, and J. Crawford. 2011b. Biology of the bearded seal (*Erignathus barbatus*) in Alaska, 1960–2009. Final Rep. Natl. Mar. Fish. Serv., Natl. Mar. Mammal Lab., Seattle, 71 p.

Table 7.—Fish and invertebrate prey diversity by stock of beluga whales in Alaska.

Stock	No. fish species	No. invertebrate species	Month
Beaufort	8	16	4–6
E. Chukchi	5	15	6–8
Kotzebue	6	9	6,7,10
E. Bering	25	22	5–7, 9,10
Bristol Bay	14	4	5–8, 10
Cook Inlet (<2002)	2	0[1]	4–10
Cook Inlet (>2002)	12	8	3,6–9,11

[1]No invertebrates were recorded during this time period likely due to field methods.

belugas and both Pacific walrus, *Odobenus rosmarus*, and bearded seals for many benthic invertebrates. Only the Cook Inlet stock is exempt from such overlap as walruses and bearded seals are not found there. Invertebrate taxonomic groups of importance to belugas that are also eaten by walrus and bearded seals include polychaetes, gastropods, bivalves, octopi, mysiids, isopods, amphipods, shrimp, crabs, echiuriids, and ascidians (Lowry et al., 1980; Fay, 1982; Quakenbush et al.[26]).

Diversity and Amount of Prey

The greatest diversity of fish prey was found in the eastern Bering Sea stock where 25 species of fish were eaten, followed by Bristol Bay with 14 species and Cook Inlet with 12 species (Table 7). The greatest diversity of invertebrates was also found in the eastern Bering Sea stock where 22 species were found followed by the Beaufort Sea stock with 16 species and the eastern Chukchi stock with 15 species.

Although we did not often determine the total amount of a prey item eaten by individual beluga whales, there were a few instances of whole fish (e.g., 12 whole coho salmon weighing 27.8 kg), numbers of otoliths (e.g., otoliths indicating a total of 951 fish eaten including 128 rainbow smelt, 390 saffron cod, and 399 Arctic cod, Table 6), and numbers of octopus beaks (e.g., > 144 for an estimated total weight of 127 kg) that suggest prey numbers and volumes consumed can be large. Such numbers indicate that, at least seasonally, beluga whales eat substantial amounts of food.

In summary, beluga whale diets in Alaska waters varies somewhat by stock, with the northernmost stocks feeding mostly on shrimp, octopus, and Arctic cod. To the south, saffron cod replaces Arctic cod and octopus is no longer prevalent. In the two most southern stocks, Arctic and saffron cod are largely replaced by salmon and smelt (rainbow smelt in Bristol Bay and eulachon in Cook Inlet). Shrimp are common prey for all beluga stocks in Alaska. Beluga whales swallow their prey whole, thus size of prey may be related to beluga size (i.e., age) although there also may be individual preferences. Younger belugas may be more limited in prey available to them. Our results may be influenced by biases due to stomach content analyses, nonrandom hunting affecting our sample of stomachs, seasonal changes in prey availability, lack of samples during winter, and other factors. Very little is known about what and how much beluga whales eat during winter and whether accumulating fat stores in summer and fall is important for survival.

Acknowledgments

We thank the many beluga hunters who provided stomachs for this study including Rex Tuzroyluk, Charles Saccheus, and Albert Simon. We also thank ADFG personnel Geoff Carroll for collecting stomachs, and Gay Sheffield, Letty Hughes, Juan Leon Guerrero, Louise Foster, Heidi Isernhagen, and others for processing them. Additional thanks go to members of the stranding response crews who collected Cook Inlet stomachs. Fish otoliths and cephalopod beaks not identified within our own lab were identified by William Walker. Noncephalopod invertebrates not identified by us were identified by Chris Stark and Ken Coyle at the University of Alaska, Fairbanks (UAF), Institute of Marine Science. Funding was provided by the Alaska Beluga Whale Committee and the Alaska Regional Office, National Marine Fisheries Service. Research was conducted under NMFS research permits 782-1694 and 10091.

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Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to the *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed double-spaced throughout and submitted with two duplicate copies. The complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, headings, subheadings, and the abstract short and clear. Because abstracts are circulated by abstracting agencies, it is important that they represent the research clearly and concisely. Headings within each section must be short, reflect a logical sequence, and follow the rules of multiple subdivision (i.e. there can be no subdivision without at least two items).

Style

The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms, abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (1984 ed.) and the CBE Style Manual (5th ed.) for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 Nov. 1991. Measurements should be expressed in metric units, e.g. metric tons as t; other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lowercase el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g. nine fish but 9 mm).

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Footnotes should not be embedded within the text document. They must be numbered with Arabic numerals and typed on a separate sheet of paper. Footnote all personal communications, listing the name, affiliation, and address of the communicator and date of communication. Unpublished data and unpublished manuscripts should include the title, author, pagination of the manuscript or report, and the address where it is on file. Authors are advised to avoid references to nonstandard (gray) literature, such as internal, project, processed, or administrative reports, wherever possible. Where these references are used, please include whether they are available from NTIS (National Technical Information Service) or from some other public depository.

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Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Coauthors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1979a, 1979b, 1979c, etc.). Authors must double-check all literature cited; they alone are responsible for its accuracy.

Tables

Tables should be printed separately and double-spaced. Tables should not be excessive in size and must be cited in numerical order in the text. Headings should be short but sufficent to allow the table to be intelligible on its own. All unusual symbols must be explained in the table heading. Other incidental comments may be footnoted with Arabic numerals. Because tables are typeset, they need only be submitted typed and formatted, with double-spaced legends. Zeros should precede all decimal points for values less than one. Table headings and format should be consistent; do not use vertical rules.

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